NUCLEAR ENGINEERING

VOL. I NO. I APRIL, 1956

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Chairman and Managing Director:
ROLAND E. DANGERFIELD

Editorial Director:
A. P. CHALKLEY, B.Sc.(Eng.)

Editor:
E. N. SHAW, B.Sc.

Head Office:
BOWLING GREEN LANE, LONDON, E.C.1
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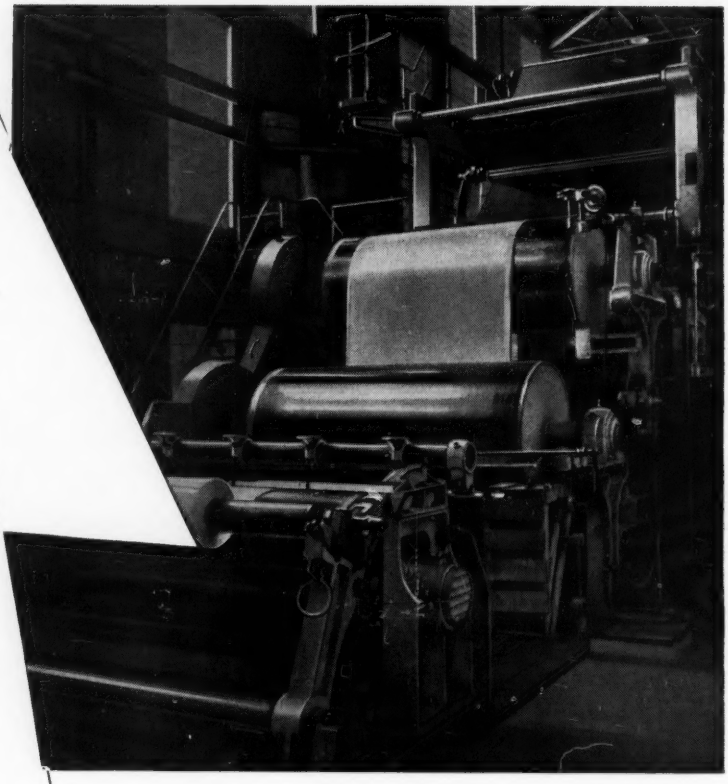
It's a Bit Thick...



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NUCLEAR ENGINEERING VOL. I NO. I APRIL, 1956

EDITORIALS

Another Industrial Revolution ?

AT no time in the technical development of man has he been so determined to herald the birth of a revolution as today. The discovery of nuclear fission has been described in many extravagant terms—as the dawn of a new era, the beginning of the millenium and so on—but we must leave history to ascribe these high-flown phrases. In the meantime it is better to examine the significance of the "Atomic Age" in its relation to its immediate industrial and sociological problems.

Its chief impact is in the prospect of a source of illimitable power or, more accurately, an illimitable source of heat—at a cost. Too often vague prophetic allusions have been made to the physical form that atomic energy may take, but fundamentally this energy is available as heat—and heat only. Uranium can, therefore, be described as a fuel in complete accordance with established terminology.

Fuel Resources

The prospect of an inexhaustible supply of fuel is by no means insignificant, but it must be remembered that only within the past few years has any serious limitation on our expansion been imposed by the difficulties of obtaining conventional fuels. Even here the limitation has, to a large extent, been economic rather than physical. In some countries supplies of fuel—oil, coal and water for hydro-electric schemes—have not been exploited to any extent: admittedly it is possible that for power these sources will never be exploited because of the advent of nuclear energy. Nevertheless it cannot be over-emphasised that uranium should be regarded simply as an alternative but readily-available fuel. The generation from it of transmittable power, such as electricity, inevitably entails the familiar problems of economics, and at present even greater problems of technology.

Much has been published on the applications of radio-isotopes, the by-products of the atomic energy programme. Here man has been presented with a new instrument for scientific and technical exploration, for material processing and for healing the sick. But radio-isotopes are not the universal panacea for troubles met in pure research, agriculture or biology. They simply represent an important extension of the techniques that have been developed over many generations. At the same time the very radioactivity that is the basis of these techniques is of considerable embarrassment in the disposing of the useless effluent from nuclear reactors. The ecological and genetic implications of the use and disposal of radioactive materials may be a serious handicap to large-scale exploitation.

Industry has a great challenge to meet in these new developments. Atomic energy is often quoted in terms of a great power for good or a great power for evil, but the division of its potentialities into these two categories is only part of the story. We are not here concerned with atoms for war. In its power for good, greatness will come only with efficiency. Nuclear energy is in direct competition with established practice.

Often industry will be involved in entirely new techniques which will require almost complete original thinking. Already a new language has been developed to describe the fundamental principles and, although this language is to a large extent simple and straightforward, it represents a stumbling-block to the engineer working on conventional plant. On the other hand much of the development required is on lines well established, where details perhaps are modified but where the basic conception remains the same. The choice between the two methods of attack will not always be obvious at the beginning of a project. Ease and cheapness will usually point to a familiar approach where well-tried principles can be applied and where experience will suffice without recourse to intuition. At other times major advances will be made only by unconventional means, frequently necessitating large capital expenditure without a sure return. It is probable that the success will be to a large extent a function of courage. A balance, therefore, must be struck between originality of thought and sureness of method, which must apply to large-scale planning and detailed manufacture alike.

Competition and Duplication

Where healthy competition between companies is allowed to flourish, some duplication of effort is inevitable. We cannot afford in this country to let this go to excess because of both manpower and material shortages. Also a compromise must be found between a completely unchannelled system of development and a stifling autocracy. This compromise has been met in the United Kingdom by the establishment of consortia with the U.K.A.E.A. acting as director-adviser and by the operation of the development contract system. As a temporary measure it has enabled the atomic energy programme to start on a firm footing with strong governmental backing, but its implied rigidity of operation will require serious modification in the years to come. Many other companies have valuable contributions to make, and of course the end product of a reactor will not always be electricity.

An extreme example of triplication was demonstrated at Geneva last August when it became obvious that in spite of intense security restrictions developments in the three main countries had moved along similar lines. The divergences that had occurred were forced by local conditions rather than by fundamental conceptions. Similar conditions will prevail in a single country unless an adequate exchange of views and information is encouraged.

Absolute Certainty

ONE of the most difficult scientific conceptions for the layman is that of probability. In spite of a considerable part of his life being built on chance, there is an instinctive reaction to terms containing uncertainties, and in science a certainty has very rarely any meaning. Seldom can one ever say more than that a theory seems to work. Similarly in engineering, irrespective of the accuracy of experimental data covering the various parameters involved in construction, considerable safety factors are always added. The net result of this is that if your nuclear engineer is to be truthful he can never give an answer to problems of safety with 100% certainty. There is invariably the "but". He may possibly go so far as to say that a particular reactor cannot be a bomb (as is usually meant by the term) but in spite of all his design efforts he can never say that it is entirely impossible for it to get out of control and become an embarrassment. This is true irrespective of the number of noughts in the mathematical chance.

The implied uncertainty inevitably must have repercussions on the general public who are looking to the engineer for concrete definitions without any possibility of error whatsoever. Whereas a statement which asserts that Calder Hall is unlikely to overheat, means to the engineer that the risk is negligible, the public tends to interpret it as indicating that there is a possibility and then even a probability of this happening and they are anxious that they personally shall not be involved. It will take continuous and steady propaganda from all sources entirely to convince the public that nuclear power stations are far less potential danger to their health than motor-cars, germs and banana skins.

The location of the experimental reactor station at Dounreay is a further indication to the lay mind that reactors as a class are a definite risk to local inhabitants. It is not easy to put over the point that when freedom of choice is available at the beginning of a project, there is no reason why one should not increase safety factors by several thousands however many millions they were to start with.

It was perhaps unfortunate that in the choice of the Bradwell-on-Sea site emphasis was laid on the relative remoteness of the location. Remoteness of course can be an advantage in the minimization of eyesores, but the not unnatural deduction by some has been that it was necessary because of safety considerations.

This is not to say that a feeling of insecurity is widespread. In fact on the opposite side of the country the proposal to build a power station has been welcomed by the local inhabitants and it must be borne in mind that the recently announced public inquiry, which is to be held on the suggested site on the east coast, has been sought by ornithologists and residents anxious to keep their isolated dwellings still isolated. Nevertheless at all times in the future where "chances" of accidents are discussed the point must be made that the term is technical and does not represent the type of hazard that the phrase conjures up.

A Scholarship in Nuclear Engineering

Temple Press Limited, publishers of *Nuclear Engineering*, will make an annual award of a post-graduate scholarship to the value of £350.

Candidates must be of British nationality, and the selection will be made by a board, shortly to be appointed.

The scholarship will be tenable at any British university. Successful candidates will be required to undertake approved studies directed towards the engineering aspects of nuclear energy.

Fuller details will be announced in the next issue of *Nuclear Engineering*.

Export Policy

THE main British effort in the field of nuclear power is being directed towards the design and construction of large graphite-moderated gas-cooled power reactors which can be fuelled with natural uranium. This type of plant is necessarily of large physical size and will be most economic in operation if it is designed for large power output; for example, an electrical output of 100 MW and upwards from a single reactor. For base load operation in the United Kingdom this is exactly what is required and there can be no doubt that the official policy of concentrating on the one type of reactor is the right policy so far as the home demand for power is concerned.

The export market for power plant, however, is mainly concerned with generating stations of relatively small size. There are very few countries outside the continent of Europe and North America where turbo-generator sets of more than 60 MW output can be justified. The overseas demand for nuclear power may therefore be confined for some years to plant in the range of output between 10 and 60 MW. Opinion is divided as to the economic feasibility of nuclear power in this range. Certainly it would be necessary to choose a reactor of relatively small dimensions, such as the pressurized water reactor, and this would involve the use of enriched fuel. The Americans have already made substantial progress with the development both of pressurized water and boiling-water reactors of moderate size using enriched uranium supplied from their diffusion plants. The economics of the use of enriched uranium have not yet been fully stated, but there appears to be a view prevalent in this country which associates enriched fuel reactors exclusively with the future availability of by-product plutonium re-cycled from the earlier "stage 1" reactors. There is thus a danger that the opening round of the export battle may be lost by the United Kingdom if the construction of a prototype reactor of moderate size is delayed to await the supply of re-cycled plutonium. It would certainly seem to be in the national interest to allocate enough fissile material from existing production plants to provide enriched fuel for one or more prototype reactors of medium size designed specially for export purposes.

Although the traditional field for the export of power plant from this country does not offer much opportunity for the graphite-moderated gas-cooled type of reactor, there is a potential market for this type of plant in the more highly developed areas of the continent of Western Europe and perhaps in Canada. So far as Western Europe is concerned, adequate facilities already exist for the fabrication and manufacture of heavy engineering equipment, and there is very little likelihood that France or Germany, for example, would wish to place orders for complete power stations to be supplied from the United Kingdom. There would, however, appear to be considerable scope for the construction of graphite-moderated gas-cooled reactor plant in these countries under licence from British manufacturers. It would be most unfortunate if this opportunity of enhancing the prestige of British engineering was allowed to pass simply because Western Europe was not regarded as our traditional export market.

Comments on the News

LOCOMOTION

In an address to the Institution of Locomotive Engineers on February 29 Sir John Cockcroft, director of the Atomic Energy Research Establishment, Harwell, outlined the present and possible future applications of atomic energy to propulsion. He pointed out that this country would be interested in the very near future in nuclear propulsion for warships and that Admiral Rickover had predicted in the United States that by early 1960 all major naval vessels authorized for construction would be propelled by nuclear power. Where cost and economics of running propulsion units are, however, of more serious importance than with naval vessels Sir John was less sanguine. The nuclear propelled merchant vessel will certainly come but not for some years yet, whereas it was improbable that the nuclear powered locomotive would ever be used, certainly in this country. The most probable application of nuclear power in the railway network would be in providing adequate electric power to enable total electrification of the system. With regard to nuclear propulsion of aircraft, Sir John pointed out some of the problems associated with a possible crash but nevertheless stated that in Britain studies on nuclear propulsion systems were being carried out by representatives of aircraft companies attached to Harwell.

At the same time it is worth noting that a number of aircraft companies in this country have announced the setting up of atomic energy sections or even separate companies. The value of a nuclear-powered aeroplane to the United Kingdom either for civil or military purposes is in our view open to question, and it is to be hoped that the feasibility studies being carried on will result in the production of reactor systems that are applicable to transportable equipment and that the fitting of them into an airframe will be accomplished only if a real pressing need arises.

DEVELOPMENT CHARGES— WHO PAYS?

The Government, which means the taxpayers, has spent millions of pounds in nuclear research, as a result of which British manufacturers will be able to supply nuclear power plants, equipment and isotopes to buyers in this country and abroad. In the normal way development charges enter into the selling price of any product and the question naturally arises whether the Government should not receive from industry part of the amount expended on research.

When the question was raised in the House of Commons recently, on the subject of the loan of nuclear fuel by the Atomic Energy Authority to Associated Electrical Industries, Mr. Butler said that the terms of the loan would cover "a percentage of the total cost of the fuel, including an element of research and development". But when he was asked how much would be paid for the "know-how" and information being given to them by the Authority, "which had cost the Authority so many millions of pounds in public money" Mr. Butler remarked that he appreciated the importance of the question, but that he "would need notice of it" before replying.

There are obvious difficulties involved, but in general principle it would seem that something equivalent to a "royalty" should be paid by the manufacturing firms. The complications include the fact that much of the expenditure has been based upon Defence requirements, and there are other problems which obviously need careful consideration in view of the magnitude of the expenditure.

The Government will have to come to some decision, if only provisional, in the near future, otherwise precedents will be created which it might be difficult to modify. No doubt further questions will be asked in Parliament, with notice, and it would be as well if policy was defined, so far as is possible.

FUEL AVAILABILITY

The statements in Parliament did little to clarify the situation regarding the availability of fuel for reactors to be built by industry either in this country (other than for the C.E.A. or A.E.A.) or abroad. It seems clear that if these reactors are to be fuelled with natural uranium, supplies will be made available and very little hold-up should be encountered. At the same time, the granting of 20% enriched fuel for the A.E.I. swimming-pool reactor has established an important precedent. The fuel elements have, of course, not been bought outright by the company but are on hire and will be returned for reprocessing. Furthermore, definite statements have been made to the effect that limited quantities of enriched fuel would be forthcoming for the building of reactors overseas.

At present no specific statement has been issued on the total quantity of concentrated fissile material that will be obtainable in the next few years for privately or overseas-sponsored reactors, whether it be plutonium or enriched uranium. Although certain deductions made from information released by Sir Christopher Hinton on the output of the Windscale piles have been rather optimistic, there is little question that a considerable quantity of plutonium and enriched uranium has been stock-piled in the United Kingdom. It is not in the national interest for this total figure to be divulged but on the other hand it is in the national interest and vital to the long-term planning of industrial concerns for a clear estimate to be made soon of the weight of plutonium and uranium 235 that can be made available for worthwhile projects. In addition a definition of "worthwhile" is required.

THERMO-NUCLEAR POWER RESEARCH

The conclusions and recommendations published in the report of the Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy in the United States of America, whilst not necessarily outlining the policy that will be adopted by the United States Government or by the Atomic Energy Commission, can be assumed, nevertheless, to have a considerable influence on future proposals.

One of the more significant recommendations is summed up in the following points:

1. The Commission within the limitations that national security considerations impose should permit the maximum interplay of scientific and engineering ideas, and develop procedures whereby more people will contribute to the controlled thermo-nuclear programme in the United States.
2. The Commission in encouraging investment in nuclear fission power should see to it that investors have sufficient information about the feasibility of nuclear fusion power upon which to base determinations for themselves as to the propriety of their investments and actions.

Such a statement can only imply that this information is there to be given and that this information is in a sufficiently concrete form for investors to be able to appreciate its significance as regards future developments.

SUBSIDIES AND SURPLUSES

The McKinney Panel also urges that not only should heavy government subsidies be used to ensure the construction of one full-scale demonstration plant of each major reactor size and type, but in addition that research programmes should receive a large measure of help. It is recommended that the A.E.C. should sell radio-isotopes at 20% of cost for use in research in fields of general science, agriculture and industry as well as in diagnosis and clinical use in medicine.

To people in the United Kingdom it must seem ironic that a warning is contained in the agricultural applications because of the probable increase in food surpluses. Nevertheless there is no suggestion that there should be any let-up on the intense research into agricultural problems, using isotopes, but that the surplus question should be tackled on a separate footing. The bulk of the information resulting from this research will be available to all countries and although it is too early to forecast its effect on future crops, the concern over the expected increased food supplies is a measure of the anticipated increase in production.

EURATOM TO DATE

It is not yet clear precisely what type of organization is proposed for Euratom, but informed opinion on the Continent appears to favour the establishment of a supra-national atomic energy authority for Western Europe which would control the operation of all the major nuclear processing plants.

The United Kingdom is faced with a difficult conflict of interests. On the one hand Britain has a unique opportunity for taking a full part in the industrial and economic life of Western Europe and of re-capturing the engineering leadership of the Continent which it enjoyed during the first half of the nineteenth century. On the other hand there is a natural and understandable reluctance on the part of any responsible government to surrender the control of industrial plants which are regarded as being vital for defence purposes.

Is it too much to hope that some formula can be found by which the United Kingdom could assume full membership of the Euratom organization while excluding its existing plants from the control of the new authority? An undertaking might for instance be given that whilst the existing British plants would continue to be operated on a purely national basis by the U.K.A.E.A., future processing plants would be built as part of the Euratom scheme. The contribution in engineering experience which the United Kingdom could make to Euratom would be of incalculable value. Any widely based European nuclear power scheme would require the construction not only of large industrial plants for fuel element fabrication and for the chemical separation of irradiated fuel but also a diffusion plant. It would be a deplorable waste of technical effort if the free nations of Western Europe were obliged to tackle such a difficult project from scratch when Britain already has the necessary knowledge and experience. A diffusion plant constructed to British designs and located in some suitable region on the Continent where reasonably cheap hydro-electric power is available would be a striking achievement for international co-operation. In return for this contribution the United Kingdom could reasonably expect to derive some corresponding gain in the supply of engineering plant and equipment.

U 235 RELEASE BY U.S. PRESIDENT

The offer by President Eisenhower of 44,000 lb. of uranium 235 for reactor projects in countries not producing fissile material has been hailed as a major step in the application of atomic energy for peaceful purposes. The implication however is inevitable that, whereas countries which at present have only embryonic atomic energy programmes will benefit, those countries such as the United Kingdom, Canada and Russia which have already spent considerable sums of money in research and development will be facing stiff opposition when they attempt to market reactors abroad. President Eisenhower's move must inevitably assure the United States of a very firm position in the export market.

RADIATION PROTECTION

The steady increase in the use of radioactive materials in industry emphasises the need for a greater appreciation of the health aspects, not only by the management in the industry but by the individuals concerned with the operations. It is not sufficient that the technical staff associated with these operations shall be cognizant of present-day rulings but that the operators themselves should be largely responsible for their own safety. Plainly they cannot take the ultimate responsibility but a fair proportion of the measurement work associated with their own protection must be handed over to them. Already the reluctance of management to delegate this function to the operators themselves is creating problems in such operations as the radiographic investigation of welding on site.

General practice is for the parent company to send to the operators small ionization chambers, previously charged, which at a later date are returned to the headquarters for checking. Such ionization chambers are, however, delicate and in many cases either arrive at the site already discharged or arrive back at headquarters completely discharged so that no knowledge can be obtained of the total dose obtained by the worker or even if the implied excessive dosage is in fact entirely spurious. The equipping of the individual radiographers, not only with ionization chambers but with charging apparatus and recording instruments, gives them an opportunity of regular checks without long time intervals between exposure and dosage information. The aggregate dosage received by a particular operator can be checked by a film badge or possibly a subsidiary ionization chamber.

Failure to make an operator responsible for his own safety must result in suspicion or carelessness quite apart from the inefficiency of the over-all check. At the same time hard and fast rules must be laid down of the exposures which are permissible not only over a protracted period but over short periods of time; that is, not only must the integrated dose be specified but also the dose rate for gamma and beta rays alike.

ICE BREAKING

It has been announced that the Russians have already firm plans for the building of a nuclear-powered ship. It is, perhaps, significant that their first long-range activity in this field should take the form of an ice-breaker. There must be a general feeling that an intensive programme of ice-breaking by the U.S.S.R. would be welcomed all over the world.

WIDESPREAD APPEAL OF "NUCLEAR ENGINEERING"

In making the announcement of the forthcoming publication of *Nuclear Engineering*, we stated that it was felt there was an urgent need for such a journal, in view of the vast and rapid development which was taking place in this new field, and of the widespread nature of the activities involved.

The results so far have confirmed our belief. Before publication of this issue we received over 3,000 subscriptions, and several hundreds are coming in every week. The reception from industry has been extremely encouraging and it will be noted that the cream of British engineering is represented in our advertising columns, including those manufacturers who are playing, and are likely to play, a leading part in the future of nuclear engineering in all its manifold aspects.

We may add that the subscriptions came from over 40 countries, in which more than 20 languages are spoken.

Training the Nuclear Engineer

Technical developments are placing an increasing load on the already strained resources of educational establishments. The shortage of trained personnel is an international problem which applies to all branches of engineering and so particularly to nuclear engineering which covers so many of these branches. Future training schemes must seek to rectify the situation by providing educational facilities not only at the atomic energy establishments, but also at the schools, universities and technical colleges.

THE development of nuclear power to the stage where industry at large is involved, has posed the problem of how the necessary specialized knowledge can be spread among the increasing number of scientists and engineers engaged in one or other aspect of the subject. Industrial concerns are already addressing themselves to the design of nuclear power stations and their associated equipment and yet, until recently, very little knowledge and experience existed outside the Atomic Energy Authority.

Fortunately, a great deal of the work which engineers are called upon to perform lies within the accumulated knowledge and experience of conventional branches of engineering, adapted in varying degree to meet a new application. Although the amount of knowledge of nuclear processes required by an individual for application to a specific item of work may be small, the total amount for an entire reactor system is large and it must reside within the organization for which the individual works.

Engineers with a knowledge of physics

Partly for this reason, there is a vital need for a body of engineers in industry who, whilst having a sound knowledge of normal engineering fundamentals and experience, have in addition sufficient understanding of the processes of nuclear energy to equip them to lead design and development work in the field, both for whole power stations and for parts of a nuclear reactor. To these two broad groups of work one may add the specialized treatment of materials new to engineering practice, liquid metal coolants for example, and the new problems of operation and maintenance of nuclear plant.

Doubtless, within a short time enough experience will have accumulated within each organization to permit most of the staff to acquire some of the knowledge necessary for their work in the time-honoured way, by learning while working, but the initial problem remains—the dissemination of knowledge to start this process.

Harwell Reactor School

The Atomic Energy Authority has for some time been active in this respect. The Reactor School was formed at Harwell in the summer of 1954 for the purpose of providing introductory courses in reactor theory and design. Many of the students have been able to continue their training either by working in reactor design in industry, or by taking part in projects at one of the Authority's establishments. The reactor design groups formed within industry are also training grounds for many who have not attended the School.

It is felt that training courses of the Reactor School type must become a permanent feature of the new industry and that they should be expanded in scope. Nuclear energy has so many new problems and will embrace so many new techniques as development goes on that there will always be a need for formal instruction. The traditional method of picking up pieces of information from practice has much to commend it, but as a training process it tends to be haphazard and should be supplemented if progress is to be maintained.

The universities and technical colleges are also playing their part and post-graduate courses of some weeks duration have been started to supplement the work being done by the Authority. These developments have of necessity depended heavily upon lecturers from the Authority staff, but here again, as the knowledge becomes more widely spread some at least of the work can be undertaken by teaching staff.

B.N.E.C.

No discussion of this subject would be complete without reference to the interesting development of the British Nuclear Energy Conference. Five major engineering and scientific professional institutions have formed this body for the purpose of providing a common ground between scientists and engineers for the discussion of the development of the technology of nuclear energy and by their efforts we may anticipate the ventilation of much valuable material. It is already becoming refreshingly clear that the period of heavy dependence upon foreign sources for published technical material is coming to an end.

Thus the initial problem of the dissemination of basic, and what may soon be termed elementary, knowledge is being tackled in several ways. These processes, together with the large number of text-books and papers now published, must mean that a working knowledge of the fundamentals will soon be widespread.

Nuclear engineering for degree work

A problem of a different kind is the influence which nuclear energy will have upon the education of engineers in universities and technical colleges. It can be said at once that a subject which spreads across the boundaries of so many conventional curricula underlines once again the necessity for the treatment of fundamental principles in the education of the young engineer. How far should nuclear engineering as a special subject figure in undergraduate courses? Should it be left for special treatment after graduation? There is a variety of opinion in the matter, but if the subject can be made a vehicle for principles and an exercise in their use there is much to be said for its inclusion as part of an undergraduate course. It at least has the advantage of being a stimulating topic at the present time. Arousing the interest of the students always solves a large part of the teaching problem. One British university has included nuclear energy for engineers in its courses for several years past. Others are following the lead and this development must lead to a further understanding of engineering as a whole in future years. Further developments at universities include the establishment of chairs in nuclear engineering and the opening up of laboratories for its experimental study. Post-graduate study can be expected to follow very soon. In short, we may hope that the better features of American educational interest may be reproduced, and improved upon, in this country.

Finally, the new range of opportunities for young engineers comes at a time when there is a great demand for them in every other branch of engineering. It is important to the country that the entry into nuclear engineering should not make the situation worse in other fields as it well might if the number of engineers of quality being produced is not increased greatly. The advent of nuclear power is one more reason for this deficiency being treated as a matter of national urgency.

Experimental Reactor Systems

PART 1

Exponential piles and zero energy reactors are logical steps in the development of high powered reactors enabling fundamental characteristics to be examined with the minimum cost and maximum safety. Details of a typical exponential experiment and critical assemblies are discussed with particular reference to the Harwell reactors.

by

R. F. JACKSON, M.A., A.M.I.Mech.E.
Assistant Director, Engineering, A.E.R.E., Harwell

IN the design of a reactor, if it is to be successful, the physicist, the metallurgist and chemist and the engineer must have reached a satisfactory compromise.

The physicist is concerned with the nuclear properties of the materials of construction, with the neutron economy of the proposed core geometry and with both the kinetics and the fuel balance of the reactor during operation. Although a new reactor type may be suggested by the engineer to provide a more attractive solution to problems of maximum temperature, heat removal, size and so on, no real progress can be made until physics calculations indicate that such a system can be made critical and will have a neutron economy consistent with the requirements. Physics method and experiment should then aim to keep in touch with the engineering development so that the effect of marginal changes in design can be predicted and perhaps exploited in the direction of improved neutron economy.

The metallurgist and the chemist are concerned with the stability and compatibility of the structural, fuel and coolant materials under the proposed conditions of radiation and temperature in addition to which the metallurgist may have to provide and fabricate relatively new and untried materials. By far the most important problem in solid fuel reactors is the fuel element. This must be able to withstand the disruptive effects of the fission products formed within itself during operation—possibly amounting to more than 2% of the total atoms—without damaging its surrounding sheath and increasing the thermal resistance of the path for heat flow to the coolant.

The engineer must see his way to a design which is safe and which ensures that the over-all cost of design, construction, operation and maintenance is commensurate with the ends achieved. Safety relates both to the design of the plant to exploit effects such as thermo-siphon cooling or negative reactivity with rising temperature in such a way as to make fault conditions fundamentally self limiting and to the design of components of the plant, especially the control and instrumentation, to minimize or anticipate faults. Much experience has been gained of both the philosophy and practice of reactor safety in the design and operation of research reactors at Harwell.

Experiments at Low Power

In any reactor, while it is operating, atoms of the fissile fuel material are being destroyed, heat energy is being created by the violence of the recoil of the fission fragments formed and two or three neutrons are released per fission of which one is required to create a further fission if the chain reaction is to continue at the same level. Many fissions per second—hence many neutrons—are associated with an appreciable rate of heat release: 3×10^{10} fissions per second are equivalent to only one watt of heat rate.

Neutrons lend themselves to detection over a very wide range of neutron flux intensity, thus a neutron counter will record the current pulses caused by individual neutrons entering its volume at rates as low as one per second while an ionization chamber may be used to record a neutron intensity perhaps 10^{12} times greater.

It is this property of reactor systems, whereby their heat output is directly related to the neutron intensity within the system, which allows accurate measurement at levels at which the heat output is infinitesimal, that makes many of the methods of obtaining experimental data very different from the experimental and pilot-plant techniques adopted in other fields of engineering. Thus the neutron flux in a small experimental assembly may be sufficient for most accurate observation and measurement at a heat output of one milliwatt while the heat output of a power reactor may be precisely known and controlled over 8 decades, say from one watt to 100 MW. Reactor experiments covering exponential and critical assemblies and zero energy reactors run at a negligible power level. They require no heat-removal equipment, very limited radiation shielding and active handling facilities and are therefore relatively simple to construct and operate. By observation of the neutron characteristics of these systems, however, much can be deduced of their physics potentialities as applied to a high power application.

The Neutron Cycle

It is well known that for a reactor to operate it must have an effective reproduction constant of greater than unity; that is, $k_{eff}>1$. The calculation of k involves the determination of the fate of all the neutrons released in fissions; $k_{eff}=1$ implies sufficient must remain from one neutron generation to cause an equal number of fissions in the succeeding generation. Now if we consider a heterogeneous thermal reactor such as a graphite uranium system, the fission neutrons will be slowed down by collisions with graphite atoms and, provided that they are retained in the reactor system and not lost through the walls, may then

(a) be captured in the graphite or in impurities in the graphite,
(b) be captured in the sheathing material round the fuel rods,
(c) be captured in impurities or alloying materials within the fuel,

Fig. 1. An exponential experiment in process. Blocks of graphite are built up to form the required matrix, the neutron flux distribution is measured under various conditions.

(d) be captured in the fuel itself without causing fission; to form U_{236} from U_{235}, or plutonium from U_{238} which, though useful, has no immediate benefit to the neutron cycle,

(e) cause fresh fissions in the fissile component of the fuel.

A small additional number of fissions may be caused by "fast" neutrons within their parent fuel rod, this effect increasing as the fuel rod diameter increases, and neutrons may be lost at certain energy stages of their slowing-down process by non-fissile capture in a "resonance trap" in a uranium fuel rod. This latter effect decreases as the fuel rods are moved farther apart, that is, as slowing down is more likely to become fully effective before further collision with uranium is experienced; it increases as the surface-to-volume ratio of the uranium increases as the resonance capture has an appreciable surface term. Resonance-trap neutrons result in increased plutonium production, hence the choice of the resonance trap effect in a particular reactor design is a nice compromise between loss of neutrons from the fission cycle and the longer-term benefits of increased plutonium production.

While methods of calculation are available for this complex problem, some empirical constants are involved and complementary experimental approach is most desirable. The simplest of these is known as the exponential experiment.

Exponential Experiments

A small section of the proposed core lattice is constructed and loaded with fissile material. An artificial neutron source is provided on one side of the assembly and by measurement of the radioactivity induced in neutron-sensitive foils, the neutron intensities throughout the system can be measured. From the exponential form of the neutron attentuation through the lattice the "goodness" of that particular geometry as a reproduction media can be deduced and expressed as the Laplacian or buckling. From this the size of a practical reactor can be calculated making suitable allowance for the neutron escape from the system and for operating margins.

The merit of the exponential approach, particularly in heterogeneous systems, is that, using considerably smaller amounts of material than would be needed to make a critical system and without the safety mechanisms and precautions that a critical system require, the goodness of a wide range of moderator and fuel dimensions can be determined experimentally.

A typical graphite exponential experiment is shown in Fig. 1. By utilizing an assortment of standard graphite building shapes, a wide range of lattice pitch and hole sizes can be arranged into which a variety of uranium rod diameters can be placed.

The core design of the power reactors at Calder Hall was checked by just such a series of graphite exponential experiments while the design of a high-pressure-water power reactor or other water uranium system would require a similar series of experiments using closely spaced uranium rods suspended in a tank of water.

Critical Assemblies

It may, however, be desirable in some instances to perform a critical assembly. In this instance the building or loading of the core is continued until it becomes divergent, giving an actual value for critical size as distinct from the uncertainty of the calculation of critical size made from an exponential experiment. Such an experiment does, however, need to be properly instrumented and have adequate control and shut-down arrangements; it does not lend itself so easily to successive modification of the core geometry over a range of dimensions of pitch and fuel size particularly for solid heterogeneous systems. In highly enriched reactors the quantities of fissile material for a critical assembly are so modest, the facilities for both a sub-critical and a critical assembly are so similar, that the latter is usually performed to eliminate the

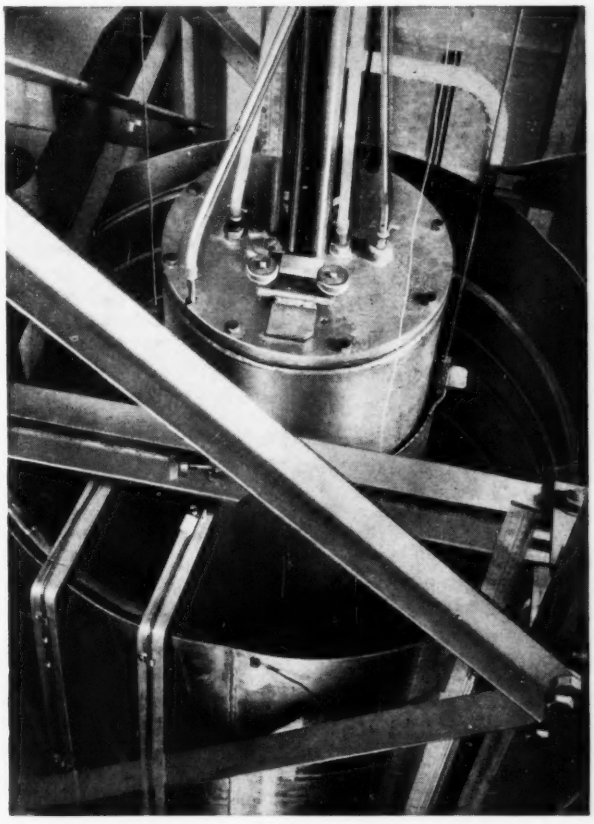


Fig. 2. ZETR—A zero energy homogeneous reactor.

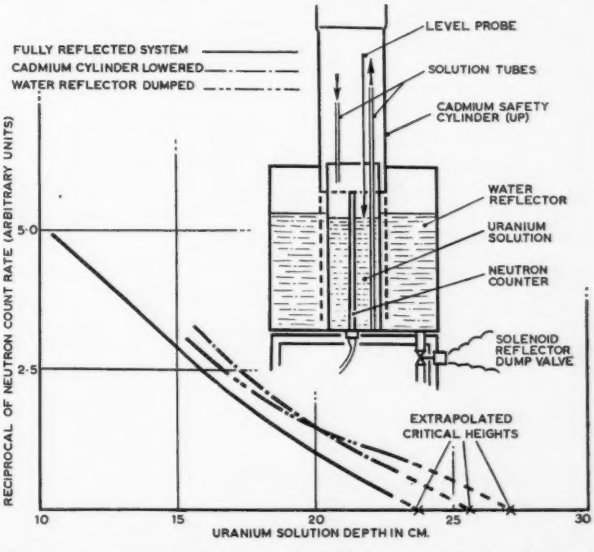


Fig. 3. Approach to criticality of ZETR. Inset shows the schematic layout of the reactor.

uncertainty of neutron leakage from a small system. Such an assembly for a solution of highly enriched uranyl sulphate is shown in Fig. 2 and has been called ZETR (Zero Energy Tank Reactor). The main components are a core tank into which the uranium solution of appropriate concentration is run from a control point, the surrounding water reflector, two cadmium safety devices and the tubes in which the boron counters fit for observing both the growth and distribution of neutron flux as the loading proceeds. A typical curve of

KEY

1. Biological shield
2. Graphite reflector
3. Lattice plates
4. Uranium elements
5. Shut off rod
6. Shut off rod winding gear
7. Experimental search tubes
8. Flux measuring ion chamber
9. Partial dump stand pipe
10. Dump lines
11. Dump valves
12. Main dump line
13. D_2O level transmitter
14. Drying connection
15. Balance line
16. Dump tanks
17. Dump tank balance line
18. Priming pump
19. Transfer pump
20. Control pump
21. Leak shrouds
22. Controlled dump valve
23. D_2O leak tank
24. Travelling top shield
25. Removable tank top

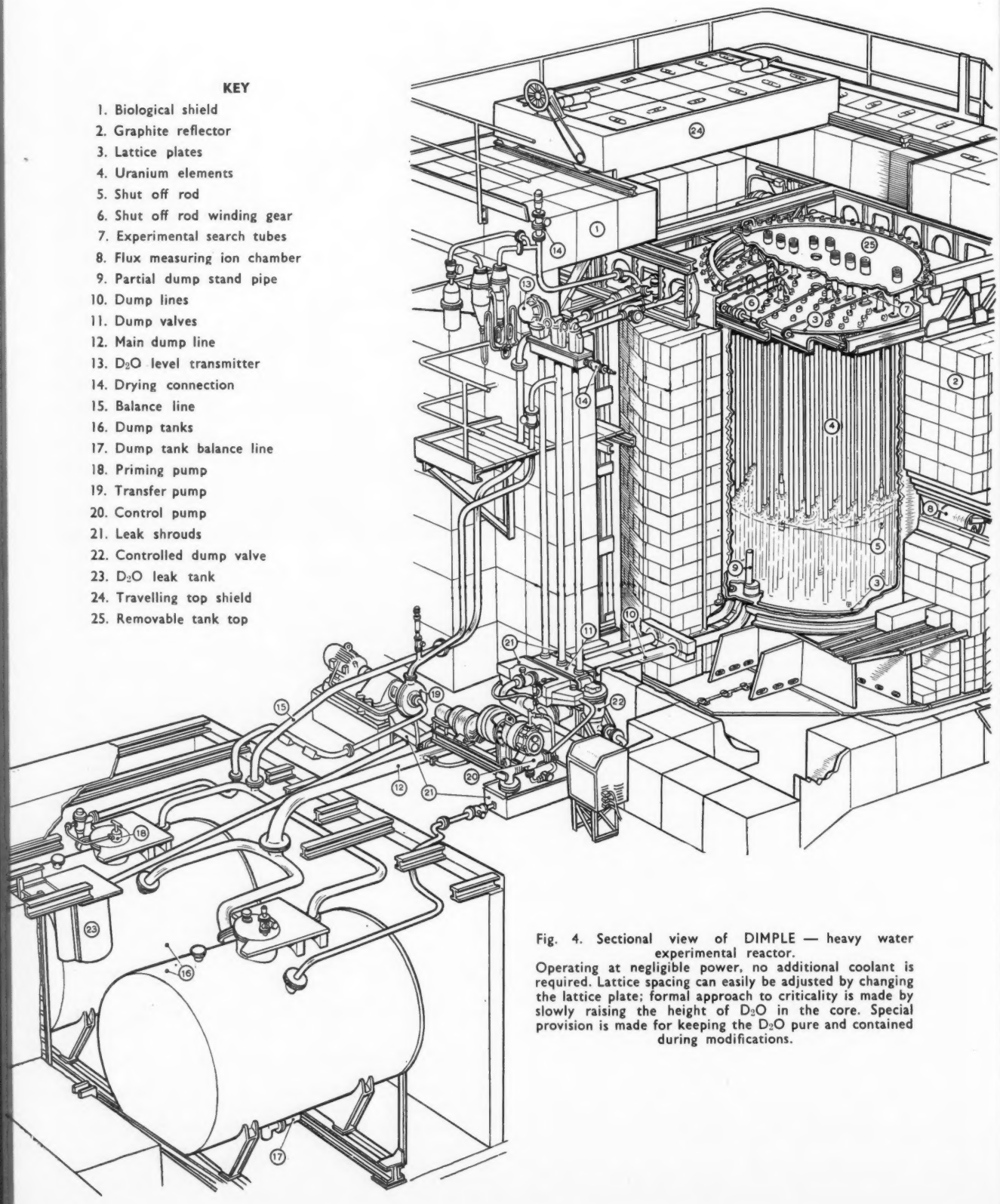


Fig. 4. Sectional view of DIMPLE — heavy water experimental reactor.

Operating at negligible power, no additional coolant is required. Lattice spacing can easily be adjusted by changing the lattice plate; formal approach to criticality is made by slowly raising the height of D_2O in the core. Special provision is made for keeping the D_2O pure and contained during modifications.

volume of solution against counting rate (Fig. 3) shows the approach to critical condition and the way in which this point can be anticipated by extrapolation during the experiment. Such experiments may be performed to provide verification of criticality calculations arising in the design of chemical plant vessels for handling fissile materials or as part of the study of a homogeneous reactor system.

Zero Energy Reactors

The last of these physics experiments is the zero energy or low power reactor. This is a reactor loaded to critical size with the full range of safety control and instrumentation equipment and capable of continued operation at powers of, say, 1-100 watts. It will require very limited radiation shielding during operation and, in general, fuel rods can be handled after shut down. Such a reactor will allow the reactor kinetics to be observed and reactivity effects of fissile and absorber loading to be measured. By irradiation of both fissile and fertile materials and of energy sensitive foils many deductions can be made of the neutron economics and breeding potentialities of the system.

Reactors in this category at Harwell include the fast reactor experiments ZEPHYR and ZEUS and the heavy-water-moderated lattice-testing reactor DIMPLE.

DIMPLE

DIMPLE, shown in Fig. 4, comprises an aluminium reactor tank some 8 ft. 6 in. in diameter and 10 ft. high supported and surrounded by a graphite reflector which is in turn surrounded by a modest radiation shield 2 ft. in thickness of concrete block construction. The heavy water is contained in storage tanks from which it can be pumped into the reactor tank and controlled very accurately at any required depth. It is retained in the reactor by two large magnetic valves which, if de-energized, allow the heavy-water moderator to drain rapidly back to the storage tank. This is one of the safety measures in the reactor construction. The uranium rods are suspended from a lattice plate in the upper section of the tank. It is the ease with which both the size of the rods and the lattice pitch may be altered on removal of the lid of the reactor tank which provides the main experimental feature of this reactor. Ten safety rods are arranged to fall into the heavy water under gravity in intermediate lattice positions. The installation includes controls and instrumentation for power level and period measurement together with automatic reactor trip and interlock circuits to prevent any incorrect sequence in the operation of the equipment.

In a typical experiment a uranium lattice spacing is chosen, perhaps involving the use of enriched uranium or containing unusual features whose effect on reactivity it is desired to measure. A calculation indicates the probable critical height. that is, the quantity of heavy water needed to be pumped into the tank before the system becomes of critical size, and further defines the effectiveness of the control and safety arrangements for this configuration.

The reactor is now subjected to a formal "approach to criticality" procedure when the heavy water is added in small increments. Meanwhile the increase in sub-critical neutron multiplication is measured and plotted against the heavy-water height in a similar way to that shown in Fig. 3. During this process the safety rods are dropped and their effectiveness measured by observation of their effect on the sub-critical multiplication. The heavy water is slowly raised to the critical level which, once determined, permits subsequent safe operation of the reactor in this lattice condition without further ado. The reactor may then be operated for several days to allow measurements of the detailed neutron flux distribution to be made across the core, to enable the effect of removal of both fuel rods and absorbers in various parts of the system to be observed and other similar investigations. A new lattice may then be substituted and the process repeated. In this way much accurate lattice data has been collected over a wide range of heavy-water-moderated systems, from which extrapolation may be made to certain aspects of light-water applications.

From an engineering point of view the 15 tonnes of 99.8% heavy water in this system must be most carefully preserved from undue chemical contamination and especially from degradation by light water. All system components are of stainless steel or aluminium and are very carefully cleaned and dried. After the heavy water has been run back to the drain tanks and before the reactor is opened up to change the lattice some 15-20 kg. of valuable heavy water adhering in droplets to the hundreds of square feet of tank surfaces are reclaimed by circulation of the air within the tank through a freezer-drier unit. After a new lattice is installed and before heavy water is admitted the air within the tank is dried of light-water vapour by circulation through an alumina drier till consistent frost points of approximately −50° C. are reached.

ZEPHYR

ZEPHYR, the first British fast reactor experiment (Fig. 5) completed in 1953, has a 6-in. diameter core of plutonium rods each some ¼ in. dia. and 6 in. long. This is surrounded by a nearly solid cylindrical array of uranium rods some 3 ft. in height and diameter containing removable inserts which provide control and safety by altering the amount of neutron leakage from the system. The reactor is again surrounded by a small radiation shield and has very complete control and instrumentation facilities to allow it to be operated at powers up to two watts. The general arrangement of the reactor is shown in Fig. 6. It has been used to provide experimental

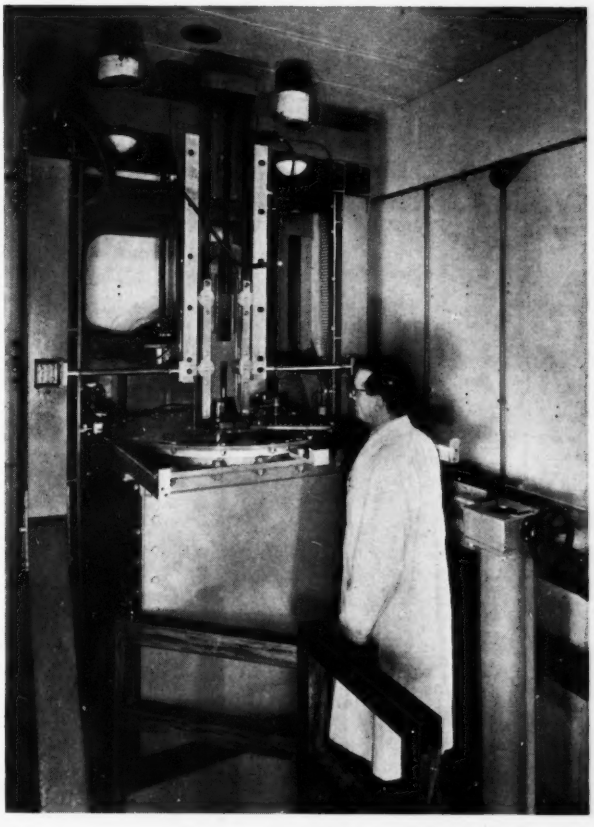


Fig. 5. ZEPHYR—the first British fast reactor. The tamper operating mechanism can be seen entering the top of the reactor which is surrounded by a minimum of shielding.

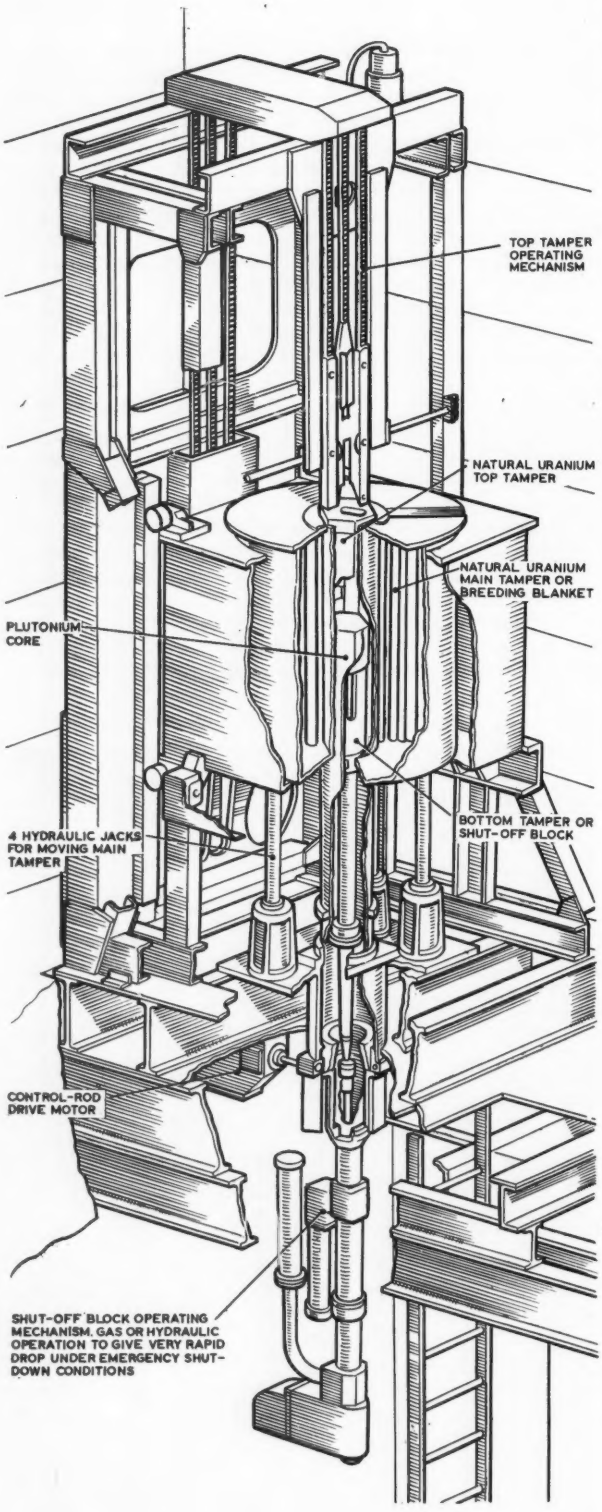

TOP TAMPER OPERATING MECHANISM
NATURAL URANIUM TOP TAMPER
NATURAL URANIUM MAIN TAMPER OR BREEDING BLANKET
PLUTONIUM CORE
BOTTOM TAMPER OR SHUT-OFF BLOCK
4 HYDRAULIC JACKS FOR MOVING MAIN TAMPER
CONTROL-ROD DRIVE MOTOR
SHUT-OFF BLOCK OPERATING MECHANISM, GAS OR HYDRAULIC OPERATION TO GIVE VERY RAPID DROP UNDER EMERGENCY SHUT-DOWN CONDITIONS

Fig. 6. A sectional drawing of ZEPHYR. The core, made up of plutonium fuel elements, is surrounded by a tamper of natural uranium. Control can be exercised by moving top or main tamper.

verification and data over a very wide range of fast reactor problems. Thus it has checked critical size calculations, allowed the determination of the delayed neutron yields in plutonium, provided quantitative data on control methods, permitted the cross-sections of many materials to be measured under various core conditions and demonstrated the feasibility of breeding; that is, of completely replenishing the burnt fuel by generation of fresh plutonium through neutrons absorbed in the uranium.

Part 2, published in the May issue of *Nuclear Engineering*, will complete the zero energy reactors with ZEUS followed by a discussion of the low-powered reactors GLEEP, LIDO, BEPO, DIDO and PLUTO.

Les Réacteurs de recherches de Harwell

On établit un rapide sommaire des données essentielles qui doivent être réunies pour la construction d'une réacteur de grande puissance. Le premier pas dans l'évaluation des données physiques nucléaires est la construction d'une pile exponentielle qui peut être modifiée avec une dépense minimum d'argent et d'effort, et pourvoira aux divers arrangements de réseau. Dans certains cas, pour des systèmes homogènes, par exemple, il est plus commode de construire un assemblage critique dès le début, ZETR est cité pour illustration. Découlant de l'expérience exponentielle, des reacteurs d'énergie zero sont construits fonctionnant avec une puissance de quelques watts. Des détails sont donnés pour DIMPLE—un système d'uranium et d'eau lourde, et ZEPHYR, le premier réacteur rapide britannique utilisant des éléments combustibles de plutonium. Dans le prochain numéro l'étude sur les réacteurs de faible puissance sera complétée par une discussion de ZEUS, et sera suivie de détails concernant GLEEP, LIDO, BEPO, DIDO, et PLUTO.

Harwell Forschungs Reaktoren

Es wird eine kurze Zusammenstellung der wichtigsten Daten gegeben, die man für die Konstruktion eines sehr grossen Reaktors braucht. Der erste Schritt in der Auswertung der Daten in der Atomkernphysik ist der Bau eines exponentialen Meilers, der mit geringsten Kosten und Kräften modifiziert werden kann, um verschiedene Gitteranordnungen auszuprobieren. In manchen Fällen, so bei homogenen Systemen, ist es bequemer eine kritische Einheit von Anfang an zu bauen, als Beispiel diene ZETR. Nach dem exponentialen Experiment werden "Null-Energie" Reaktoren konstruiert mit einer Leistung von einigen wenigen Watt Einzelheiten von DIMPLE werden gebracht—wo mit Uranium und schwerem Wasser gearbeitet wird—und ZEPHYR, dem ersten britischen schnellen Reaktor, in dem Plutonium Brennstoffelemente benutzt werden. In den nächsten Heften wird der Bericht über Reaktorenleistung durch eine Besprechung von ZEUS, vervollständigt werden, worauf Einzelheiten über GLEEP, LIDO, BEPO, DIDO und PLUTO folgen werden.

Reactores de Harwell para Investigaciones

Se hace un sumario breve de los datos esenciales que deben ser reunidos para poder diseñar un reactor de elevada potencia. El primero paso en hacer una avaluación de los datos de física nuclear es el de construir una pila atómica exponencial, la que, con costo y esfuerzo mínimos, pueda ser modificada para varias disposiciones alveolares. En algunos casos, tales como con sistemas homogéneos, es más conveniente construir un conjunto crítico desde el principio, y de esto se toma a ZETR como un ejemplo. Después de terminado el experimento exponencial, se construyen reactores de energía a cero, funcionando a una potencia de unos cuantos vatios. Se ofrecen detalles de DIMPLE—un sistema uránico de agua pesada, y ZEPHYR, el primer reactor británico rápido usando elementos de plutonio como combustible. En el próximo número, se completarán los reactores de baja potencia con una discusión sobre ZEUS, la que será seguida de los detalles de GLEEP, LIDO, BEPO, DIDO y PLUTO.

The Harwell Reactor School

by

SIR JOHN COCKCROFT, K.C.B., C.B.E., F.R.S.

Director, Research Group, United Kingdom Atomic Energy Authority

The school offers a three months course on nuclear engineering for students well grounded in the fundamentals of physics or engineering. Foreign students can now be accepted and the course has been extended to include practical experiments on BEPO.

THE first official course at the Harwell Reactor School started in September, 1954, although a trial course had been given the previous spring to a group of industrial representatives who were working at Harwell at that time. The school was instituted because there was a need to train those men from industry who would be engaged on design studies for future power reactors (in accordance with the proposals made in H.M. Government's White Paper, *A Programme for Nuclear Power*). At that time the courses held at the school were secret and only British subjects could attend them. However, in August, 1955, an international conference on the peaceful uses of atomic energy was held in Geneva under the auspices of the United Nations. At this Conference, a very large amount of information on reactor technology was publicly released for the first time; indeed, the amount of "declassification" which took place at Geneva was so great that it became possible to hold completely unclassified courses at the Harwell school, and meant, of course, that foreign students could attend. Accordingly, the first international course started in September, 1955, when roughly one half of all the students attending were from overseas.

The school is now in the middle of its fifth official course, and, as one might expect in such a young school, each course differs somewhat from all the previous ones. The evolutionary character of the courses is such that it is difficult to give an exact description of a standard course; however, a description of the present one will give a good idea of the general nature of the curriculum.

At the moment, the school caters primarily for graduate engineers and physicists, and, therefore, the main subjects taught are reactor engineering and reactor physics. As backgrounds to these subjects, groups of lectures are also given on chemistry, chemical engineering, metallurgy, and health physics. In the early part of the lecture syllabus, there are some lectures on basic nuclear physics for those engineers who have had no previous training in this field; on the other hand, there are lectures on fluid flow, principles of heat transfer and thermodynamics for the physicists who have not had experience in the problems of extracting heat from power plants.

All the students then attend lectures on reactor theory and reactor engineering. In the case of reactor theory, they are taught how to calculate the critical size of a reactor and how to evaluate the various quantities which influence that critical size, such as the effects of temperature rise in the reactor and poisoning due to the accumulation of fission products. A few more advanced reactor theory lectures are given towards the end of the course for those students wishing to specialize; such subjects as control rod calculations and the variation in reactivity of a pile with time of irradiation of the fuel are dealt with.

Also, in the reactor physics lectures, the students are taught how to design biological shields, and they hear about the various kinds of measurements which can be made with research reactors. Lectures are given on exponential and critical experiments and on the subject of fuel cycles, that is, they are shown the various ways in which the fissile material bred in a reactor can be used in an expanding power programme.

Sir John Cockcroft welcoming overseas students to the first international course at the school.

In the engineering lectures, the students are taught how to calculate heat transfer rates, temperature distributions in reactors, thermal stresses and the pumping power required to circulate the coolant. The kinetic behaviour of a reactor is considered, and the various ways in which a reactor can be controlled are discussed in detail. Lectures are given on the necessary instrumentation for reactors, which, besides covering the measurement of power level, deal with the mechanisms for shutting-down a reactor and the ways in which burst cartridges can be detected.

Some of the more specialized nuclear engineering techniques such as the design of electro-magnetic pumps for circulating liquid metal coolants are also covered in the engineering lectures. This group of lectures concludes with descriptions of the various possible types of power reactors, pointing out their advantages and disadvantages, and showing how to estimate the probable cost of electricity, produced from them.

In the chemistry and chemical engineering lectures, such subjects as the manufacture of pure moderators and fuels and the processing of irradiated fuel elements in order to extract the bred fissile material and fission products are described. The metallurgy lectures cover the properties of uranium, thorium, plutonium and other metals used in reactors, the fabrication of fuel elements and their behaviour under irradiation, and various special topics such as the corrosion of fuel-element cartridges by coolants. The health physics lectures describe the measurement and control of the radiation dosages received by reactor operators, and the important subjects of reactor safety and radioactive effluent disposal.

The course is of three months' duration and four lectures are given on every Monday, Wednesday and Friday, the other days being spent on experimental work. There are therefore about 150 one-hour lectures, of which about 100 are devoted

to physics and engineering. On the lecture days there is only one lecture in the afternoon, the remainder of the time being spent in private study or in informal discussion with the lecturers—a most valuable part of the course.

Besides the lectures, there are classroom periods when the students are shown how to solve particular problems and, spread out over the whole course, the students work through a complete design of a power reactor.

Almost every lecturer is a research worker in the field covered by his lecture; in other words, our general policy is not to have full-time lecturers, as such people find it difficult to keep abreast of the latest developments in their own field.

Although a small amount of practical work has been done by the students on previous courses, we are experimenting on the present course with our first large-scale programme of practical work. The students will carry out an exponential experiment and measure the slowing-down length of fast

Three Indian students at the Reactor School talking to Sir John.

neutrons in graphite in two experiments which are sited in the Graphite Low Energy Experimental Pile (GLEEP) compound. They will also work on the larger graphite-moderated pile, BEPO; where they will compare thermal neutron absorption cross-sections with a pile oscillator and investigate the variation of cross-section with neutron energy of a number of elements using a Fermi type slow chopper. They will measure the neutron flux variation across an experimental hole in BEPO, and also will find the effect on the reactivity of the pile of inserting an absorber in various positions in this hole. In addition, they will take part in running BEPO from a cold unpoisoned condition to full power. Before beginning these experiments in the GLEEP and BEPO areas, the students will be familiarized with the use of health monitoring instruments, and instructed in the measurement of neutron fluxes using irradiated foils and Geiger counters.

At the school itself there is a reactor simulator so that the students can study various problems in reactor kinetics.

By the time the next course begins, we hope to supplement these experiments with a shielding experiment on BEPO, using a steel and water shield, and a liquid-metal rig for studying the characteristics of electro-magnetic pumps and calibrating flow meters.

During each course the students make a number of tours of the Atomic Energy Research Establishment. They visit the chemical engineering division several times where, amongst other things, they see a plant for extracting uranium 233 from thorium. During their tour of the metallurgy division they see uranium being cast and fabricated. They pay visits to two of Harwell's reactors: ZEPHYR, a zero-energy fast reactor, and DIMPLE, a low power heavy-water moderated reactor. They also visit the site for DIDO where the latest high-flux research reactor is being built. They are shown the latest health physics instruments in operation, see the design and development of remote-handling tools, and visit the effluent farm for an afternoon.

About mid-way through the course, when the students have begun to appreciate some of the difficulties in producing power from nuclear energy, they pay a whole-day visit to the Calder Hall power-station site in the north of England. Here, members of the industrial group give them talks on the power-station and take them on an extensive tour of it.

Having dealt with the school in its present phase of development, we can now turn to the future plans for the school. It was recently decided that the present school buildings are too cramped and unduly restrict the number of students attending each course (the present attendance is about 30 students per course and there are three courses per year, giving an annual throughput of about 100 students). Therefore we have started to build a new school which will be ready by the summer of this year. The new school will accommodate about twice as many students as the present one, and we believe that this is as many students as can be managed in order that they may all receive some individual attention. Furthermore, there will be a large laboratory attached to the school, and we shall be able to install a number of heat transfer experiments and, in addition, metallurgical and chemical experiments.

So far as the longer-term plans for the school are concerned, we would like to see the Universities and Technical Colleges take over from us all the fundamental training in nuclear physics and basic reactor engineering. If we could assume that every student attending a course at Harwell had a good knowledge of the fundamentals of the new science of nuclear engineering, we could then use the Harwell school to the best advantage and give specialist courses in various branches of reactor technology. In these circumstances, the Harwell school would fulfil the role for which it is uniquely suited in this country; namely, giving instruction in advanced aspects of reactor technology, the teachers being people who are actively working in the fields concerned.

L'Ecole Réacteur de Harwell

Une centaine d'étudiants passent chaque année par l'école réacteur de Harwell Angleterre. Des ingénieurs qualifiés et des physiciens du monde entier suivent un cours de trois mois sur les principes de la technique nucléaire. Des conférences sur la physique nucléaire, la théorie des réacteurs, et son application sont complétées par des visites aux points clefs des établissements de l'U.K.A.E.A., et par des expériences pratiques sur GLEEP et BEPO. Une certaine spécialisation est possible vers la fin du cours. On construit en ce moment de nouveaux bâtiments qui permettront d'agrandir ce stage en champ et capacité.

Die Harwell Reaktor Schule

Hundert Studenten gehen jährlich durch die Reaktorenschule in Harwell in England. Qualifizierte Ingenieure und Physiker aus der ganzen Welt lernen die Grundlagen der Kernkrafttechnik in dreimonatigen Kursen. Vorlesungen über Atomkernphysik, Theorie des Reaktors und Reaktortechnik werden ergänzt durch Besuche in den wichtigsten Abteilungen der Werke der U.K.A.E.A. und durch praktische Experimente in GLEEP und BEPO. Eine gewisse Spezialisierung kann gegen Ende des Kurses vorgesehen werden. Zur Zeit werden neue Gebäude errichtet, um sowohl den Bereich der Kurse als auch ihre Aufnahmefähigkeit zu erweitern.

La Escuela de Reactores de Harwell

Cien estudiantes por año pasan por la escuela de reactores en Harwell, Inglaterra. A los ingenieros y físicos diplomados de todas partes del mundo se les enseña las bases fundamentales de la ingeniería nuclear en un curso de estudios que dura tres meses. Se suplementan las conferencias sobre física nuclear, teoría del reactor e ingeniería del reactor mediante visitas a las partes de mayor interés de los establecimientos de la U.K.A.E.A. (Autoridad de Energía Atómica del Reino Unido) y por experimentos prácticos sobre GLEEP y BEPO. Hacia fines de los cursos es posible cierta especialización. En la actualidad se están construyendo nuevos edificios para ampliar los cursos, tanto en esfera de acción como en capacidad.

Power and the Central Electricity Authority

The Central Electricity Authority has embarked on an ambitious programme for the utilization of nuclear power in which it and the U.K.A.E.A. will collaborate closely. The first power stations to be built will employ gas-cooled graphite-moderated natural-uranium reactors of the Calder Hall type.

by

J. ECCLES, C.B.E., M.M., B.Sc., M.I.C.E., M.I.E.E., M.I.Mech.E.

Deputy Chairman, Operations, Central Electricity Authority

THE main function of the Central Electricity Authority is to develop and maintain an efficient, co-ordinated and economical system of electricity supply. For that purpose they are required to generate electricity and provide bulk supplies to the Area Boards, who are responsible for the distribution and sale to consumers in their respective areas.

Whilst there is a perfectly legitimate field for the use of privately-owned generating plant, the bulk of the generating plant in Great Britain is owned and operated by the Electricity Supply Authorities and it is their responsibility, and theirs alone, to meet the public demand for electricity whenever and wherever it may occur.

The Nuclear Power Programme

It is in the above context that one should view the *Programme for Nuclear Power* issued by the Government in the form of a White Paper on February 15, 1955. This document outlines a provisional 10-year programme for the introduction of nuclear power to the electricity supply system of the United Kingdom, and an indication of probable developments in the further 10-year period up to 1975. Twelve nuclear power stations will be built and brought into commission by 1965, and will provide a generating capacity of between 1,500,000 kW and 2,000,000 kW.

Construction of the first two stations is programmed to begin in 1957 and operation will commence in 1960-1961. Further stations will follow, until, by 1965, generation from nuclear fission should be replacing 5 to 6 million tons of coal a year which otherwise would need to be burned in generating electricity at conventional stations.

The commercial application of nuclear power in Great Britain will probably take place in three stages, each being progressive in terms of technology and power output.

The first stage, which we are now entering, should provide power stations which will generate electricity at a cost comparable with that from coal-fired stations, after taking credit for the valuable by-product, plutonium, which is produced during the fission process. This plutonium can be stockpiled, and subsequently used for the more advanced reactors in the later stages of the development, or for slight enrichment of fuel charge in improved versions of first stage reactors. The initial stations, each having an output capacity of about 200,000 kW, will employ gas-cooled graphite-moderated reactors using natural uranium as the fuel. It is believed that not only will these stations be economical in the conditions which at present prevail in the United Kingdom, but also that they are capable of considerable development. Capital cost per kW may well be more than double that of coal-fired stations at the outset, but fuel costs will be comparatively low and both these costs should be reduced as techniques are improved. The development of new uranium alloys, canning materials, other coolant gases and so on, must in time lead to greater economy in the capital cost and operation of gas-cooled reactors.

The second and third stages of development should, respectively, see the introduction of liquid-cooled enriched-fuel reactors giving higher heat ratings and improved thermal efficiency, and breeder reactors in which the amount of new fissile material produced will be equal to or greater than the quantity of fissile material consumed. Nevertheless, the gas-cooled graphite-moderated reactor is best suited for the immediate needs of the country and will not be outmoded by the subsequent development of reactors using enriched fuel.

In the case of England and Wales, the Central Electricity Authority will construct, own and operate all the nuclear power stations to be provided as part of their supply system under the nuclear power programme. Similarly, the South of Scotland Electricity Board and the North of Scotland Hydro-Electric Board will own and operate any stations in their respective Areas.

A Co-operative Adventure

In October, 1955, the Central Electricity Authority announced that the sites on which they proposed to build the first two power stations would be at Bradwell on the Essex coast, and Berkeley in Gloucestershire. These are the first projects to be designed and constructed for the primary purpose of generating electricity. Their design is based largely on that of the experimental plant now nearing completion at Calder Hall in West Cumberland.

The Calder Hall station is owned by the United Kingdom Atomic Energy Authority. Its prime function is to produce plutonium for military purposes and electricity is only a useful by-product. This electricity will be purchased from the U.K.A.E.A. by the Central Electricity Authority. Further development is taking place on the Calder Hall site and similar works are being constructed by the U.K.A.E.A. at Annan in Dumfriesshire. The seeming contradiction in the functions of the two respective organizations in respect of electricity generation is easily explainable by the fact that the U.K.A.E.A. stations are basically designed as plutonium producers for the military programme but producing some electricity as a by-product and giving valuable construction and operating experience for the C.E.A. stations. In that sense the U.K.A.E.A. appears to be fulfilling two tasks; meeting the military requirements and doing the pioneering work on reactor design.

The first C.E.A. stations use the same basic design calculations but the reactors will be of much higher rating and the emphasis will be on the maximum economy in the cost of power that is consistent with safe technical design.

The U.K.A.E.A. have been concerned with reactor design and development and have given and will continue to give valuable advice on the preparation of the enquiry specification for the nuclear portion of the C.E.A. stations. Both organizations have agreed to consult together in the final selection of the reactors offered to C.E.A. by the industrial concerns which are tendering for the work.

The U.K.A.E.A. must continue to design and build prototype reactors and once these are proved the information gained will be made available for incorporation in the C.E.A. commercial stations. There is an agreement between the two organizations that detailed plans for commercial stations shall be mutually acceptable. Each Authority is keeping the other informed of any improvements in technology which would improve the efficiency of electricity generation.

Various companies have been given an opportunity of acquiring valuable experience in the nuclear power field through the design and construction contracts for the Calder Hall reactors, and others have contracts for design studies of more advanced types of experimental reactors.

Specifications for the first two commercial stations have been issued to the four industrial groups, and they are now working on the detailed designs under the guidance and with the co-operation of the U.K.A.E.A. Competitive tenders are being submitted towards the end of this year, and it is hoped that site construction will start early in 1957.

Although there must be a certain amount of conjecture about the cost of electricity generated by nuclear energy, present estimates indicate that nuclear power can be made to compete with any other form of power generation, and may well result in cheaper electricity in the future. In the present fuel situation we must accept economic risks whilst using all the ingenuity we possess to insure against them.

A.E.I. Research Reactor

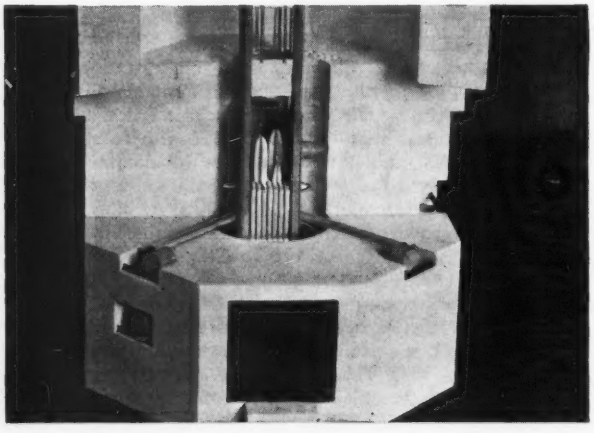
AN order has been received by A.E.I.—John Thompson Nuclear Energy Co. Ltd. to build a research reactor at the A.E.I. research laboratories, Aldermaston. The reactor will be of the swimming pool type and it is to used for general nuclear research work. A.E.I. have also announced that they are prepared to make facilities available for its use by universities, technical colleges and research institutions for undergraduate and post-graduate instruction.

The reactor will be known as MERLIN, a contraction of Medium Energy Research Light-water-moderated Industrial Nuclear reactor. This reactor has been planned for some months and recently the Atomic Energy Authority announced that fuel would be made available for its construction. The reactor will be owned by A.E.I. but fuel itself will be effectively on hire indefinitely. The only conditions that have been laid down concerning the supply of fuel are that appropriate costs will be paid for fabrication, reprocessing, U 235 spent and some development work.

The reactor will be constructed in a building 60 ft. diameter and 47 ft. 3 in. high. The core can be moved in the coolant pool in the vertical direction into one of two positions to increase the available experimental facilities. In the first position these will consist of two graphite thermal columns 7 ft. 4 in. by 4 ft. 6 in. square, one 12 in. diameter beam hole, three 6 in. diameter beam holes and a central hole in the core 3 in. by 3 in. In the second position there will be two 6 in. diameter through tubes, four 6 in. diameter beam tubes, two 8 in. diameter vertical tubes, a central hole in the core 3 in. by 3 in. and a shelf able to take an object 2 ft. cube up to the core.

The water acts as moderator, coolant and shield. Forced circulation of the water ensures a low temperature of operation but natural convection in the event of a shut-down will maintain the core at a safe temperature. The reactor has a high negative temperature coefficient of reactivity and boiling will reduce the reactivity even further.

Power level is determined by four ion chambers situated on the corners of the core and by a fission chamber at the core centre. A complex system of interlocks guards the reactor against damage through mal-operation.



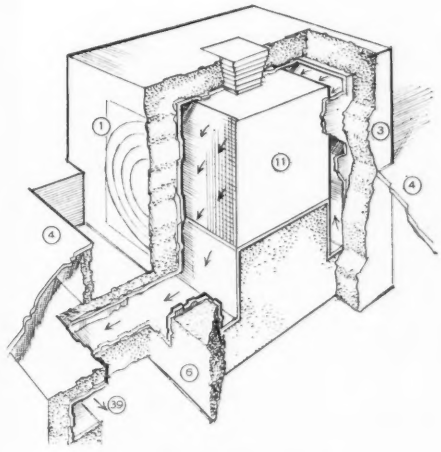
Sectional view of the reactor core and experimental facilities of MERLIN. Safety rods are shown raised.

Preliminary Specification

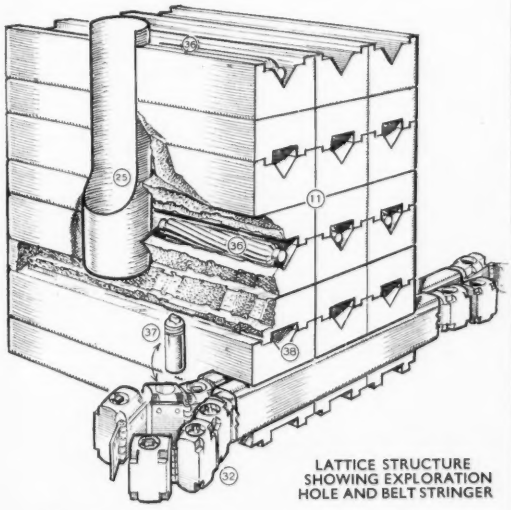
Materials:	
Fuel	Uranium oxide (U—20% U_{235}) 4.5 kg. U 235—hot, poisoned and with experimental absorbers, contained in boxes each about 3 in. x 3 in. x 24 in. holding 12 plates.
Dimensions:	
Core	2 ft. 3 in. x 2 ft. 3 in. x 2 ft.
Reflector	3 in. or 6 in. thickness of H_2O on sides, 4 ft. min. H_2O top and bottom.
Shield	13 in. water, 6 ft. 3 in. barytes concrete sides, 18 ft. 6 in. min. water top.
Over-all	28 ft. high, 16 ft. 6 in. across flats.
Operating Conditions:	
Total thermal power	Normal 1 MW; 5 MW max.
Coolant inlet temperature	35° C.
Coolant outlet temperature	45° C.
Max. fuel temperature	92° C.
Max. sheath temperature	90° C.
Coolant velocity in core	2.5 ft./sec.
Pumping rate	1,600 g.p.m.
Pumping power required	120 h.p. at 5 MW.
Fuel consumption per day of operation	1 gm. U 235 at 1 MW.
Cooling System:	
Type	Recirculated water.
Coolant treatment	Filter and demineralization plant.
Pumps	2 x 1,000 g.p.m. pumps, 1 operating 1 standby at 1 MW.
Safety	Natural convection, Boiling.
Controls:	
Fine	0.5% reactivity, Cd sheet in Al container.
Coarse	8% reactivity, Cd sheet in Al container.
Safety	2 x 8% reactivity, Cd sheet in Al container.
Fuel Handling:	
Discharging	Used elements stored in reactor shield.
Physics (preliminary calculations, cold unpoisoned):	
Resonance escape (p)	0.96
Thermal utilization (f)	0.75
Diffusion length (L)	1.65 cm.
Slowing down length (L_s)	7.36 cm.
Laplacian	.0085 $cm.^{-2}$
Infinite multiplication factor k_∞	1.50
Radiation Fluxes (at 5 MW):	
Epithermal neutrons (max)	2 x 10^{14} $n/cm.^2/sec.$
Thermal neutrons (max)	5 x 10^{13} $n/cm.^2/sec.$
γ-Radiation (edge of core)	2 x 10^8 rad/hr.

KEY

1. Load face
2. Unload face
3. Control face
4. Main floor level
5. Load platform
6. Concrete shielding
7. Cast iron
8. Stepped plug
9. Air space
10. Bridge section
11. Graphite blocks
12. Thermal column
13. Lead door
14. Bismuth
15. Cast iron floor
16. Steel plating
17. Sniffer cabinet
18. Sniffer mechanism
19. Shut-off rods
20. Shut-off rod shock absorber
21. Shut-off rod
22. Jack covers
23. Jack operatin
24. Experimental
25. Experimental
26. Control rods
27. Rack and pin

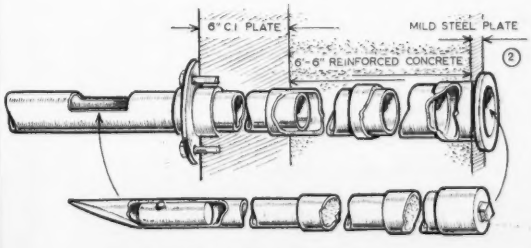


DIAGRAMMATIC PICTURE OF PILE

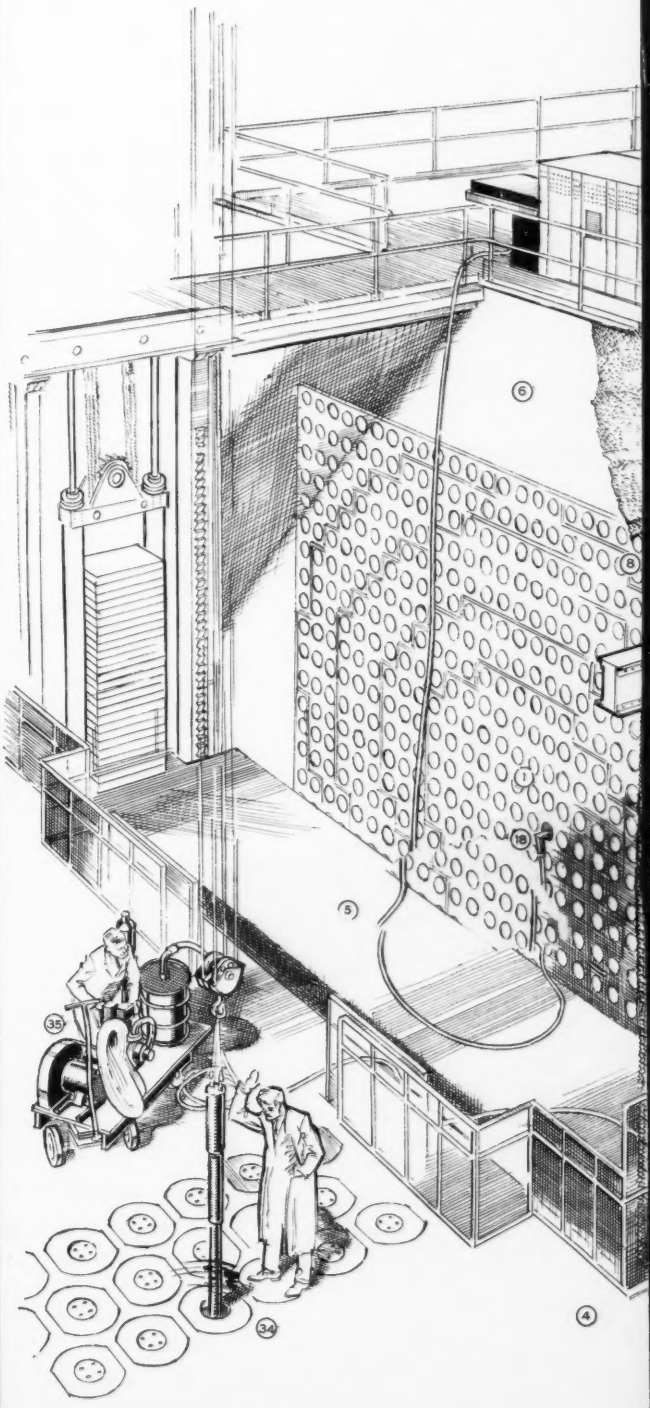


LATTICE STRUCTURE SHOWING EXPLORATION HOLE AND BELT STRINGER

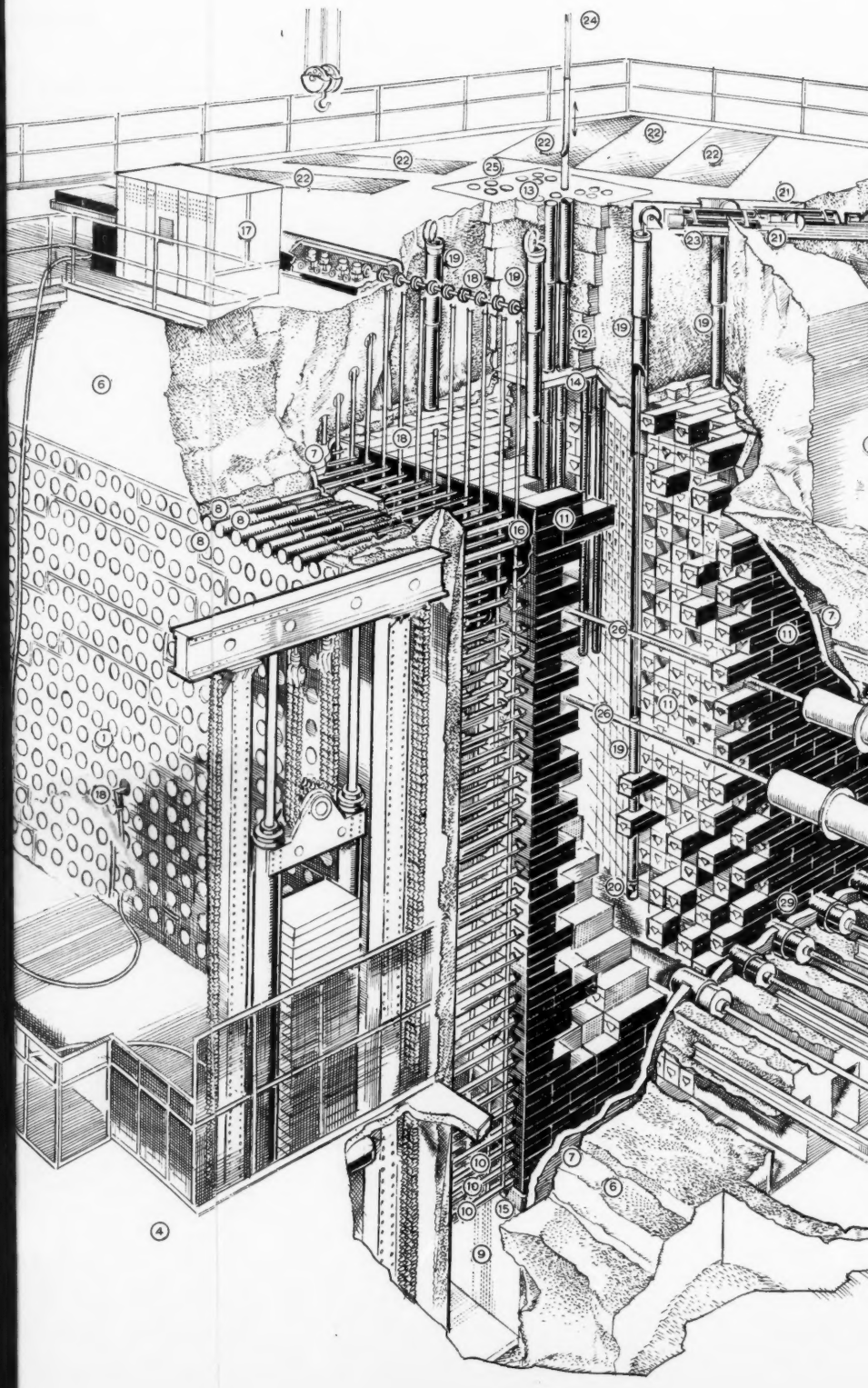
FUEL ELEMENT



AIR INLET VALVE ON EACH COOLANT CHANNEL



21. Shut-off rod jacks
22. Jack covers
23. Jack operating cylinders
24. Experimental probe
25. Experimental holes
26. Control rods
27. Rack and pinion
28. Pinion operating motor
29. Ionization chamber
30. Lead coffin
31. Belt stringer control
32. Belt stringer
33. Lead trolley
34. Mortuary
35. Vacuum decontamination machine
36. Fuel element
37. Isotope can
38. Fuel and coolant channels
39. Outlet duct



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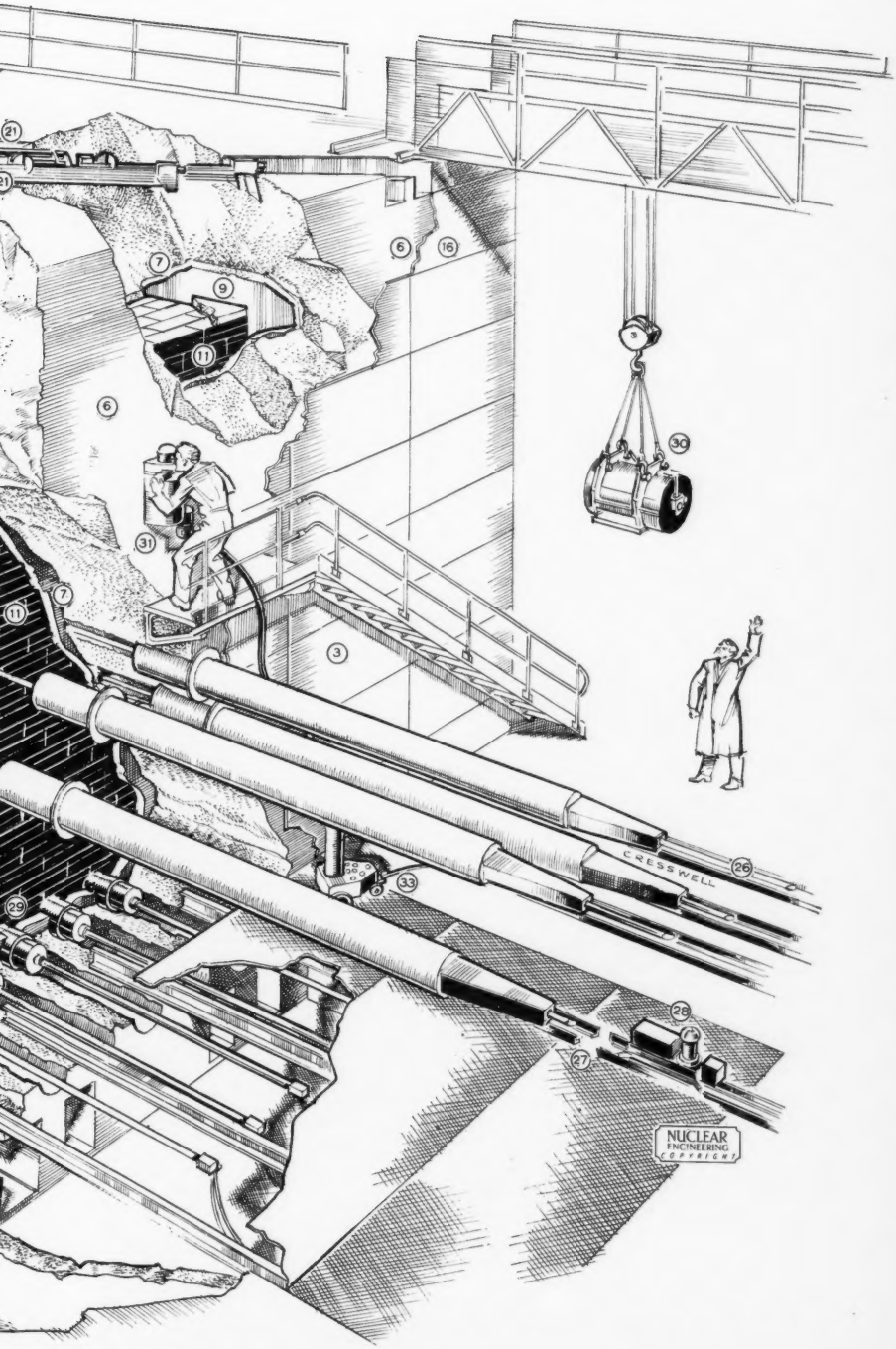
The World's Reactors
No. 1—BEPO



The World's Reactors No. 1

BEPO—BRITISH EXPERIMENTAL PILE

TYPE:	Thermal heterogeneous.
PURPOSE:	General research using pile radiations. Routine production of radio-isotopes. Some low-power engineering loop experiments.
LOCATION:	Harwell, near Didcot, Berkshire, England.
OPERATION:	Commenced operation July 5, 1948.
FUEL:	Natural uranium. U as cast bars, 0.9 in. dia. 12 in. long, Al clad. Elements laid in stringers of 20 per coolant channel. Reacting core: 20 ft. dia. x 20 ft. long. Total number of fuel channels: 900. Charge for criticality: 28 tons. Charge for operation: 40 tons. Maximum fuel temperature: 250° C.
FUEL CANS:	Pure aluminium, 99.5 to 99.7% purity. Wall thickness 0.025 in.; helical longitudinal fins. Sheath temperature 200° C.
MODERATOR:	Graphite. Form: mainly machined blocks, $7\frac{1}{4}$ in. x $7\frac{1}{4}$ in. x 29 in. Total wt.: 850 tons. Geometry: cube 26 ft. on the side. Mean temperature: 95° C.
REFLECTOR:	Graphite: 3 ft. all round core.
LATTICE:	Regular square $7\frac{1}{4}$ in. pitch
LATTICE CONSTANTS:	Thermal utilization factor (f) = 0.8795. Fast fission factor (ϵ) = 1.0249. Neutron fission factor (η) = 1.276. Resonance escape probability (p) = 0.9200. Infinite multiplication factor (k_∞) = 1.0587. L_s = (slowing-down length)^2 = 410 cm.^{2} L_d = (diffusion length)^2 = 303 cm.^{2} Critical buckling for bare pile (B^2) = 0.825 m.$^{-2}$
COOLANT:	Air. Inlet: from atmosphere through filter. Outlet: through filter and suction pump. Pile pressure: about 60 in. water. Inlet coolant temperature: atmospheric. Outlet coolant temperature: 90° C.
PUMPING:	Pumping equipment: five 1,400 h.p. (11,000 volt) exhausters. For full power working: three operative. Air flow: 150,000 c.f.m. approx. Inlet filter: cotton wadding. Outlet filter: oil-sprayed glass-fibre mats.
POWER:	Normal operating power: about 6.5 MW heat. Recovery: 1 MW via heat exchanger for space heating.
FLUX:	Maximum thermal neutron flux: about 1.5 x 10^{12}, n/cm.^{2}/sec.
CONVERSION:	U^{238} to Pu^{239}. Conversion factor approx. 0.75.
BURN-UP:	One charge of fuel will last five to ten years.
REACTIVITY:	Excess reactivity: 1.4%, freshly charged.
CONTROL:	Shut off rods: 10. Control rods: 4. Rod construction: B_4C-filled 2 in. steel.
SHIELDING:	Six in. thick cast iron thermal shield backed by barytes concrete biological shield 6 ft. 6 in. thick. Weight of shielding: about 5,000 tons. Thermal shield: 600 tons in addition to above.

A limited supply of separate copies is available of this series of data sheets on various reactors built or projected throughout the world. Copies may be obtained from the publishers, Temple Press Limited, Bowling Green Lane, London, E.C.1, at the cost of packing and postage only (4d. each).

Portable Radiation Monitors

Precision of operation may not be compatible with a wide variety of usage. The limitations of individual instruments are discussed with relation to the desirable characteristics that should be aimed at by a manufacturer. General agreement has been reached on ranges and energy sensitivity.

by

D. TAYLOR, Ph.D., M.I.E.E., F.Inst.P.

Head of Electronics Division, A.E.R.E., Harwell

IN its simplest form a radiation measuring instrument comprises three main components. These are: the radiation detector; the measuring element with its indicating system; and the power supply unit. In one form of apparatus the detector could be a Geiger counter, the power supply unit a high-voltage battery, and the measuring element a counting-rate meter with a microammeter in its output. There are many possible variations of this system each with its own problems of design.

The same instrument, with minor changes, may fulfil a variety of purposes, such as uranium prospecting where, by detecting the presence of the emitted gamma rays and by using a standard geometry it would be possible (and is in fact usual) to calibrate the meter reading in U_3O_8 content in the ground surveyed. Other applications in which the instrument may be employed are detecting the presence of radiation and evaluating the health hazard in the working areas around nuclear reactors, particle accelerators, and so on. For a gamma-sensitive detector the instrument would then be calibrated in roentgens per hour.[1] Instruments of the same type can also be used in a standard geometry to determine the amount of radioactive contamination on personnel, and clothing, and the calibration might then be in terms of microcuries (μC) per unit area, or sometimes in counts per unit area. These instruments, known as survey meters and contamination meters, belong to a class called health instruments, because of their use in health hazard evaluation. They also find application, or will do so if atomic weapons are ever used again as weapons of war, in determining the extent of contamination and assessing the hazard to health in devastated areas. Health instruments which would be used by a civil defence worker after an atomic bomb attack are designated radiological defence, or radiac,[2] instruments.

Survey Meter Design

Directional Characteristics—Survey meters, whether they are required for prospecting, health physics measurements, or radiological defence require a careful layout to ensure good omni-directional characteristics over the required solid angle of detection. This is important not only in connection with the over-all performance of the apparatus but also with its calibration. A geological prospecting instrument used for assessing the uranium content in topsoil, or a survey meter used for measuring the dose rate due to deposited contamination on the ground (say due to radioactive "fall-out"), must have good omni-directional characteristics over the lower 2π solid angle. Instruments of this type are invariably calibrated using a point source (radium or cobalt 60 and a calibration method must be adopted which takes account of the way the apparatus is normally employed otherwise gross errors can result. On the other hand an instrument which is used for health physics purposes in a laboratory may be allowed to have more marked directional characteristics, since the source of contamination producing the radiation hazard is likely to be confined to a small area. Conditions in practical use then correspond almost exactly to those of calibration with a point source. It is a good maxim therefore in designing survey meters to have a very complete knowledge of the instrument's directional characteristics, and to make sure that this information is made available to the user.

If an instrument is to monitor mono-energetic radiation, then it can be calibrated with the same radiation, but frequently an instrument has to make measurements of radiations covering a wide spectrum of energies. It is necessary therefore to appreciate the limitations of a calibration at one energy. For example, Fig. 1 shows the change in the sensitivity characteristics of one type of survey meter when checked (a) with 1.2 MeV gamma-radiation and (b) with 0.16 MeV gamma-radiation. It will be noted that the sensitivity is

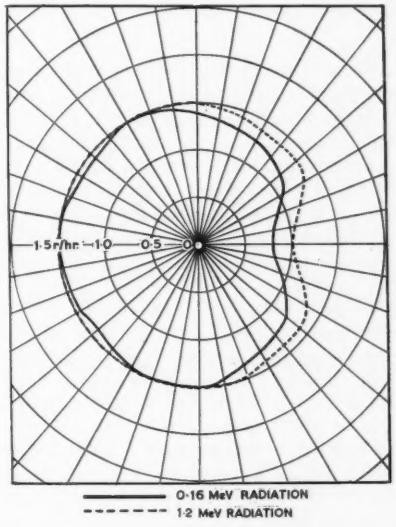


Fig. 1. Typical characteristics of a survey meter, showing variation in response in horizontal plane.

reduced by about 25% in the least favourable direction when checked with low-energy radiation as compared with 1.2 MeV radiation. This is, of course, due to absorption in the battery compartment which is at the back of the meter. The reduced performance is limited to a very narrow angle (about 20°) while the solid angle involved is about 7% of 4π. The correction here will therefore be very small when concerned with a source giving rise to equal dose rates over the lower 2π.

It should also be remembered that portable instruments of this type are carried by the observer, whose presence has an influence on the reading. When the instrument is used for locating a source of small area contamination, the observer can stand behind the instrument with the contamination

[1] To overcome the limitation imposed by the roentgen unit, the International Commission on Radiological Units (1954) recommended that the fundamental unit of ionizing radiation should be concerned with "absorbed dose," that is the amount of energy imparted to matter by ionizing particles per unit mass of irradiated matter at the place of interest; also that the absorbed dose should be expressed in terms of the "rad," which is 100 ergs per gram of irradiated material. As the numerical differences are slight, the I.C.R.P. have also recommended that for whole body exposure to X-rays and γ rays with photon energies less than 3MeV, the dose expressed in rads shall be numerically equal to the dose expressed in roentgens. The majority of the instruments available at the present time are calibrated in roentgens or in the case of radiations other than X-rays and γ rays in roentgens-equivalent-physical (rep), but rads are gradually coming into use.

[2] Radiac is a contraction of radioactivity, detection, identification and computation.

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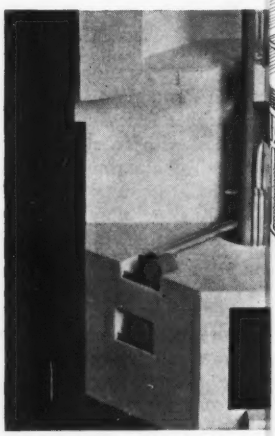

Sectional view of the reactor
MERLIN. Safe

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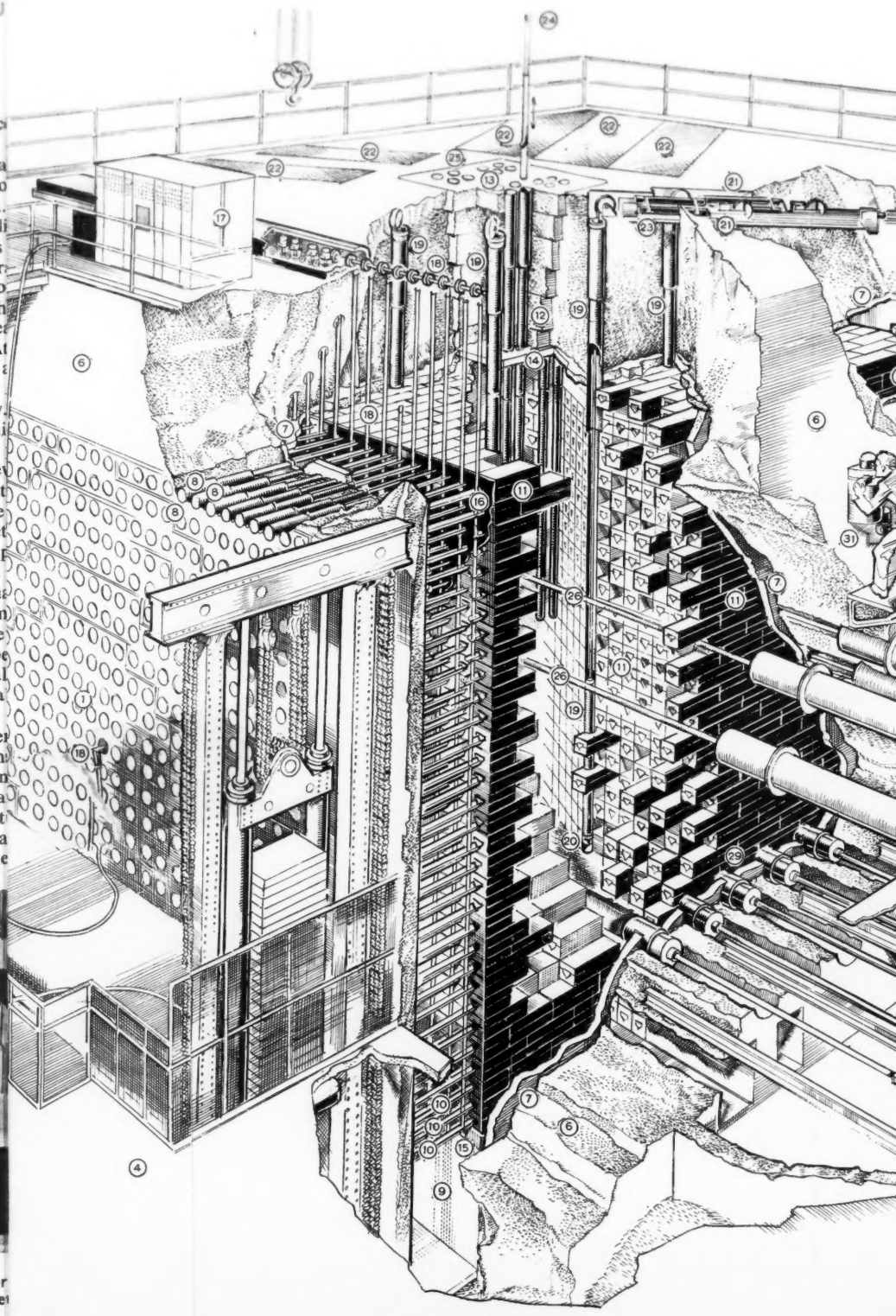
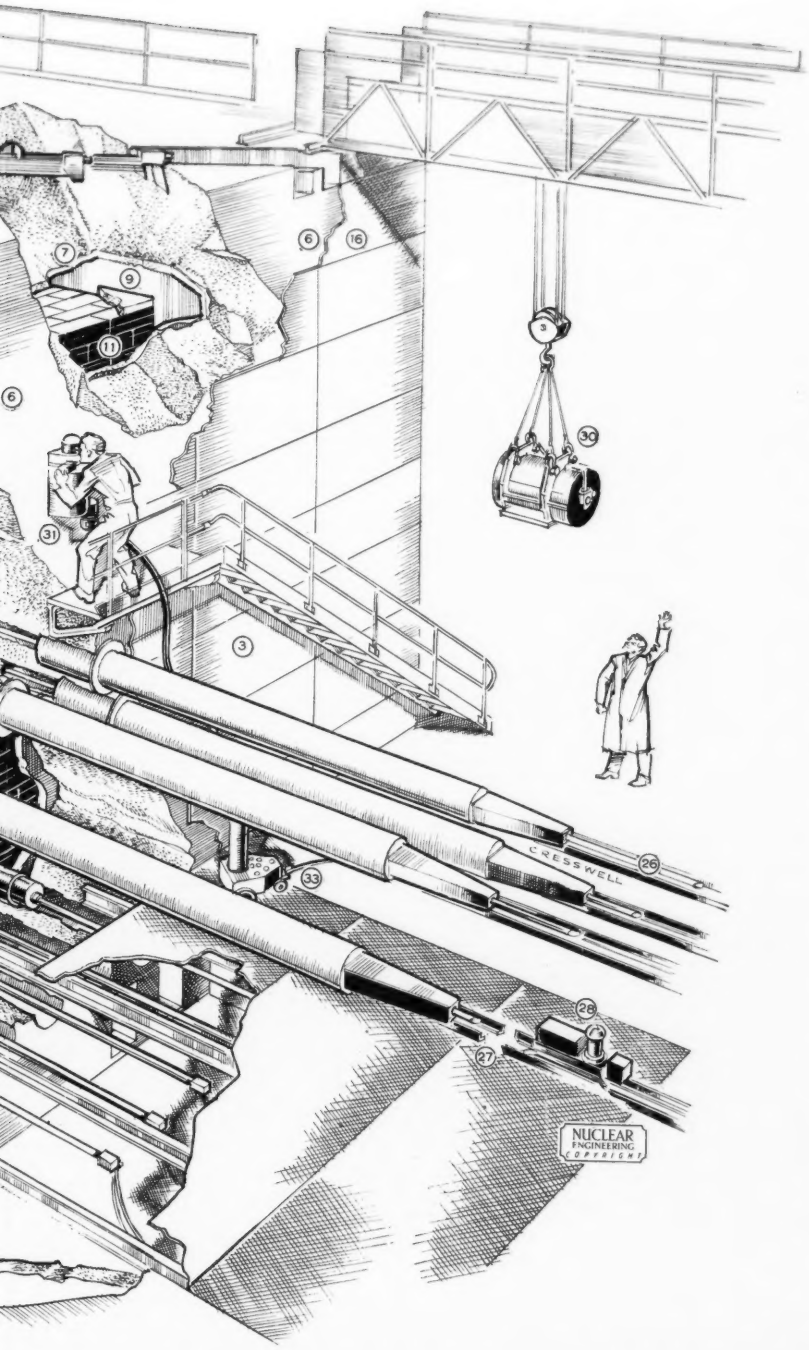


The World's Reactors No. 1—BEPO



Monitors

by

D. TAYLOR, Ph.D., M.I.E.E., F.Inst.P.

Head of Electronics Division, A.E.R.E., Harwell

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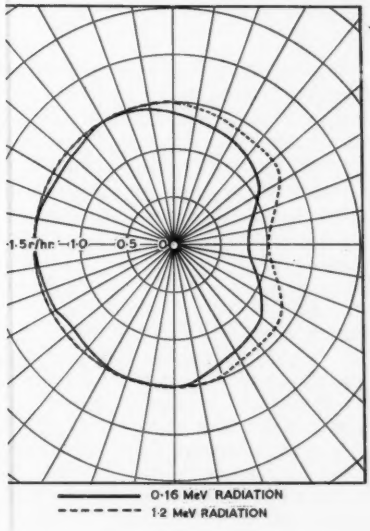

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also be remembered that portable instruments of
carried by the observer, whose presence has an
the reading. When the instrument is used for
ource of small area contamination, the observer
behind the instrument with the contamination

The World's Reactors No. 1

BEPO—BRITISH EXPERIMENTAL PILE

TYPE:	Thermal heterogeneous.
PURPOSE:	General research using pile radiations. Routine production of radio-isotopes. Some low-power engineering loop experiments.
LOCATION:	Harwell, near Didcot, Berkshire, England.
OPERATION:	Commenced operation July 5, 1948.
FUEL:	Natural uranium. U as cast bars, 0.9 in. dia. 12 in. long, Al clad. Elements laid in stringers of 20 per coolant channel. Reacting core: 20 ft. dia. x 20 ft. long. Total number of fuel channels: 900. Charge for criticality: 28 tons. Charge for operation: 40 tons. Maximum fuel temperature: 250° C.
FUEL CANS:	Pure aluminium, 99.5 to 99.7% purity. Wall thickness 0.025 in.; helical longitudinal fins. Sheath temperature 200° C.
MODERATOR:	Graphite. Form: mainly machined blocks, $7\frac{1}{4}$ in. x $7\frac{1}{4}$ in. x 29 in. Total wt.: 850 tons. Geometry: cube 26 ft. on the side. Mean temperature: 95° C.
REFLECTOR:	Graphite: 3 ft. all round core.
LATTICE:	Regular square $7\frac{1}{4}$ in. pitch
LATTICE CONSTANTS:	Thermal utilization factor (f) = 0.8795. Fast fission factor (ϵ) = 1.0249. Neutron fission factor (η) = 1.276. Resonance escape probability (p) = 0.9200. Infinite multiplication factor (k_∞) = 1.0587. L_s^2 = (slowing-down length)^2 = 410 cm.^{2} L_d^2 = (diffusion length)^2 = 303 cm.^{2} Critical buckling for bare pile (B^2) = 0.825 m.$^{-2}$
COOLANT:	Air. Inlet: from atmosphere through filter. Outlet: through filter and suction pump. Pile pressure: about 60 in. water. Inlet coolant temperature: atmospheric. Outlet coolant temperature: 90° C.
PUMPING:	Pumping equipment: five 1,400 h.p. (11,000 volt) exhausters. For full power working: three operative. Air flow: 150,000 c.f.m. approx. Inlet filter: cotton wadding. Outlet filter: oil-sprayed glass-fibre mats.
POWER:	Normal operating power: about 6.5 MW heat. Recovery: 1 MW via heat exchanger for space heating.
FLUX:	Maximum thermal neutron flux: about 1.5 x 10^{12}, n/cm.^{2}/sec.
CONVERSION:	U^{238} to Pu^{239}. Conversion factor approx. 0.75.
BURN-UP:	One charge of fuel will last five to ten years.
REACTIVITY:	Excess reactivity: 1.4%, freshly charged.
CONTROL:	Shut off rods: 10. Control rods: 4. Rod construction: B_4C-filled 2 in. steel.
SHIELDING:	Six in. thick cast iron thermal shield backed by barytes concrete biological shield 6 ft. 6 in. thick. Weight of shielding: about 5,000 tons. Thermal shield: 600 tons in addition to above.

A limited supply of separate copies is available of this series of data sheets on various reactors built or projected throughout the world. Copies may be obtained from the publishers, Temple Press Limited, Bowling Green Lane, London, E.C.1, at the cost of packing and postage only (4d. each).

Portable Radiation Monitors

Precision of operation may not be compatible with a wide variety of usage. The limitations of individual instruments are discussed with relation to the desirable characteristics that should be aimed at by a manufacturer. General agreement has been reached on ranges and energy sensitivity.

by

D. TAYLOR, Ph.D., M.I.E.E., F.Inst.P.

Head of Electronics Division, A.E.R.E., Harwell

IN its simplest form a radiation measuring instrument comprises three main components. These are: the radiation detector; the measuring element with its indicating system; and the power supply unit. In one form of apparatus the detector could be a Geiger counter, the power supply unit a high-voltage battery, and the measuring element a counting-rate meter with a microammeter in its output. There are many possible variations of this system each with its own problems of design.

The same instrument, with minor changes, may fulfil a variety of purposes, such as uranium prospecting where, by detecting the presence of the emitted gamma rays and by using a standard geometry it would be possible (and is in fact usual) to calibrate the meter reading in U_3O_8 content in the ground surveyed. Other applications in which the instrument may be employed are detecting the presence of radiation and evaluating the health hazard in the working areas around nuclear reactors, particle accelerators, and so on. For a gamma-sensitive detector the instrument would then be calibrated in roentgens per hour.[1] Instruments of the same type can also be used in a standard geometry to determine the amount of radioactive contamination on personnel, and clothing, and the calibration might then be in terms of microcuries (μC) per unit area, or sometimes in counts per unit area. These instruments, known as survey meters and contamination meters, belong to a class called health instruments, because of their use in health hazard evaluation. They also find application, or will do so if atomic weapons are ever used again as weapons of war, in determining the extent of contamination and assessing the hazard to health in devastated areas. Health instruments which would be used by a civil defence worker after an atomic bomb attack are designated radiological defence, or radiac,[2] instruments.

Survey Meter Design

Directional Characteristics—Survey meters, whether they are required for prospecting, health physics measurements, or radiological defence require a careful layout to ensure good omni-directional characteristics over the required solid angle of detection. This is important not only in connection with the over-all performance of the apparatus but also with its calibration. A geological prospecting instrument used for assessing the uranium content in topsoil, or a survey meter used for measuring the dose rate due to deposited contamination on the ground (say due to radioactive "fall-out"), must have good omni-directional characteristics over the lower 2π solid angle. Instruments of this type are invariably calibrated using a point source (radium or cobalt 60 and a calibration method must be adopted which takes account of the way the apparatus is normally employed otherwise gross errors can result. On the other hand an instrument which is used for health physics purposes in a laboratory may be allowed to have more marked directional characteristics, since the source of contamination producing the radiation hazard is likely to be confined to a small area. Conditions in practical use then correspond almost exactly to those of calibration with a point source. It is a good maxim therefore in designing survey meters to have a very complete knowledge of the instrument's directional characteristics, and to make sure that this information is made available to the user.

If an instrument is to monitor mono-energetic radiation, then it can be calibrated with the same radiation, but frequently an instrument has to make measurements of radiations covering a wide spectrum of energies. It is necessary therefore to appreciate the limitations of a calibration at one energy. For example, Fig. 1 shows the change in the sensitivity characteristics of one type of survey meter when checked (a) with 1.2 MeV gamma-radiation and (b) with 0.16 MeV gamma-radiation. It will be noted that the sensitivity is

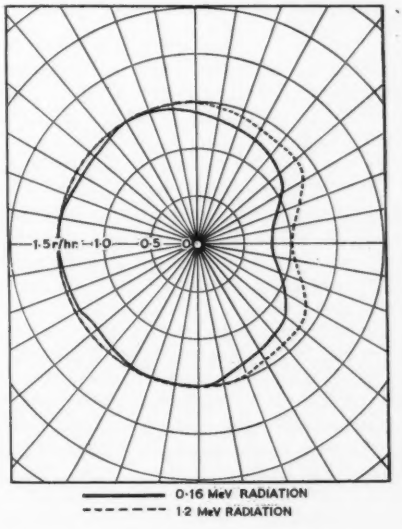


Fig. 1. Typical characteristics of a survey meter, showing variation in response in horizontal plane.

reduced by about 25% in the least favourable direction when checked with low-energy radiation as compared with 1.2 MeV radiation. This is, of course, due to absorption in the battery compartment which is at the back of the meter. The reduced performance is limited to a very narrow angle (about 20°) while the solid angle involved is about 7% of 4π. The correction here will therefore be very small when concerned with a source giving rise to equal dose rates over the lower 2π.

It should also be remembered that portable instruments of this type are carried by the observer, whose presence has an influence on the reading. When the instrument is used for locating a source of small area contamination, the observer can stand behind the instrument with the contamination

[1] To overcome the limitation imposed by the roentgen unit, the International Commission on Radiological Units (1954) recommended that the fundamental unit of ionizing radiation should be concerned with "absorbed dose," that is the amount of energy imparted to matter by ionizing particles per unit mass of irradiated matter at the place of interest; also that the absorbed dose should be expressed in terms of the "rad," which is 100 ergs per gram of irradiated material. As the numerical differences are slight, the I.C.R.P. have also recommended that for whole body exposure to X-rays and γ rays with photon energies less than 3MeV, the dose expressed in rads shall be numerically equal to the dose expressed in roentgens. The majority of the instruments available at the present time are calibrated in roentgens or in the case of radiations other than X-rays and γ rays in roentgens-equivalent-physical (rep), but rads are gradually coming into use.

[2] Radiac is a contraction of radioactivity, detection, identification and computation.

directly in front, and the effect of his presence is then very slight. However where the radioactivity covers a wide area, as with radioactive fall-out, and the radiation is received at the meter over a large solid angle (so that the observer must in any case stand between the meter and a part of the source) the position of the observer may have a most pronounced effect. This is shown in Fig. 2, the outer curve corresponding to the measured performance without an observer in close proximity to the meter. In general, it is found that the presence of the observer causes a reduction in the measured dose rate by 10% to 15%. There are two aspects of this effect for the designer to consider. First, he should plan the layout of his instrument so that the two curves are as symmetrical as possible. A rough correction can then be applied if necessary to the observed dose rate by adding a constant percentage. Secondly, the designer may consider employing a calibration method which takes account of the way the survey meter will be used in practice, but to claim a very high precision for a simple survey meter used under a variety of conditions is unreasonable. An over-all precision of measurement of $\pm 25\%$ is difficult to obtain, particularly when it is necessary to cope with a wide spectrum of gamma-ray energies.

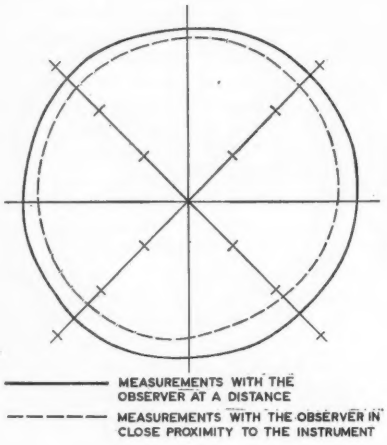


Fig. 2. Polar diagram showing the effect of the observer's proximity to the survey meter.

There is, of course, an alternative approach to this problem when a higher precision of measurement is absolutely necessary, and that is to increase the complexity of the apparatus and to place the measuring head at a distance from the observer (Fig. 3). Here the radiation detector and its associated head amplifier are mounted at one end of a metal tube and the main amplifier unit at the other. The instrument is carried by a strap over the shoulder and the detector head is normally about 3 ft. in front of the observer. This instrument allows dose-rate measurements over an energy range 65 KeV to 2 MeV with a precision of about $\pm 10\%$ even for a widely dispersed contamination.

Energy Characteristics.—Most survey meters for health physics or radiological defence purposes are designed to be sensitive to gamma-radiation, but it is sometimes desirable that they be made sensitive to beta-radiation. This is usually arranged by providing a thin window in the radiation detector through which beta-particles can pass, which is covered when a "gamma only" measurement is required. With the cover removed the instrument responds both to beta and gamma-radiation, so that if both are present a differential measurement allows the existence of a potential beta-hazard to be determined. The possibilities and limitations of this beta measurement are discussed later. For the present it should be noted that to measure the true gamma-dose a certain wall thickness in the detector is necessary. It is generally agreed that this should be about 1,500 milligrams per sq. cm., although a thickness of only 1,000 milligrams per sq. cm. is often regarded as adequate as the use of the lower thickness only introduces an error of about 2% to 3% at the most. However, it is important that the detector should have "air-wall" characteristics. The sensitivity/energy relationship can be made almost flat from about 70 KeV upwards. Fig. 4 shows what has been achieved in this way for one of the British survey meters.

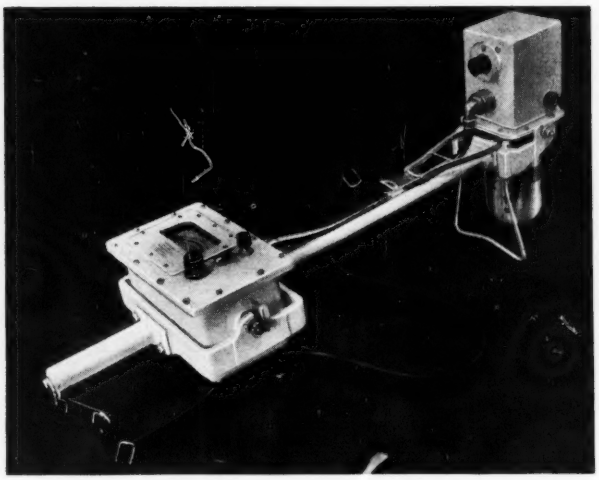


Fig. 3. A survey meter of novel design, in which the measuring head is placed at a distance from the observer.

It may be noted here that attempts have been made to produce instruments with flat characteristics extending below 70 KeV, but for most purposes this is unnecessary. The biological response to ionizing radiations varies considerably with energy of the incident radiation at low values. It is not yet clear how a radiation measuring instrument should be designed to take account of this, but it is generally agreed that an instrument which has a falling characteristic (i.e. reduced sensitivity) below about 70 KeV is desirable. Instruments which have an accentuated response at low energies give a false impression of the radiation hazard.

It is possible to use other radiation detectors, such as Geiger counters, scintillation counters, conductivity counters, in survey meters but, in general, sensitivity/energy characteristics are not as good. They can be adequate for survey work but at the same time other desirable features may have to be sacrificed—low voltage Geiger counters, for example, introduce serious difficulties. A good characteristic is obtainable from a scintillation counter incorporating a composite crystal of anthracene and cadmium tungstate, and relatively good results have been obtained from a cadmium sulphide cell in association with a plastic phosphor.

It may be helpful here to refer to the use of certain glasses

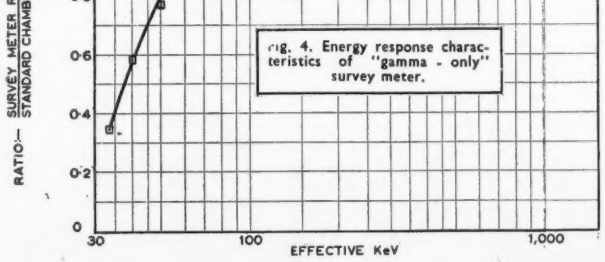


Fig. 4. Energy response characteristics of "gamma - only" survey meter.

which contain meta-phosphate salts as radiation detectors. These glasses fluoresce under UV light after exposure to radiation, the intensity of fluorescence providing a measure of the radiation dose. This is a radiation detector whose sensitivity varies markedly with energy in the low-energy part of the spectrum, but it is possible to correct this by the use of a filter with a small window. Fig. 5 shows what can be achieved in this way and includes some information on the directional characteristics. Of course the best way to obtain good omni-directional sensitivity would be to use a completely symmetrical shape. Here this was not possible but serves to illustrate what can be achieved in a compromise design.

Returning now to the question of the beta-window, it is useful to remember that the provision of such a window in an ionization chamber instrument inevitably affects the perfor-

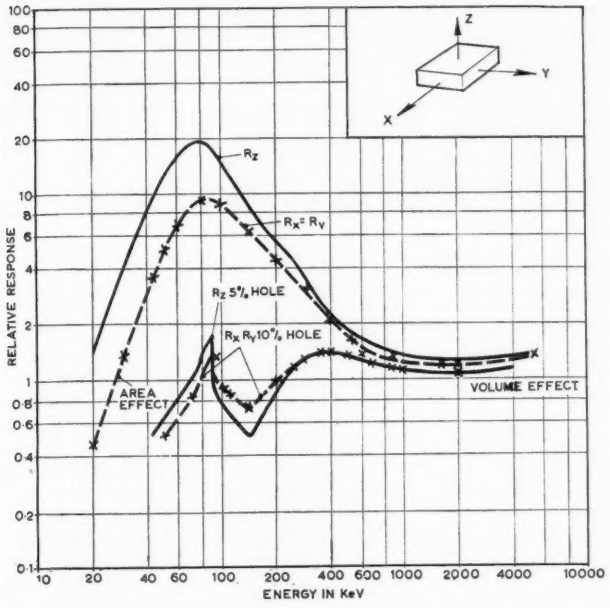


Fig. 5. Energy response characteristics for glass dosimeters.

mance of the composite instrument when used with gamma-radiation. Hence, when reasonably high precision measurements are the aim, it is good plan to avoid an all-purpose design. As an example, Fig. 6 shows the gamma-sensitivity/energy characteristics for a survey meter with a beta-window (a) covered and (b) with the cover plate removed, when tested with "gamma only" radiation.

Further Design Problems.—The majority of survey meters which have been designed for health physics and similar purposes use ionization chambers as the radiation-detector component, and electrometer valve circuits as the measuring component. To ensure a satisfactory performance with such a survey meter it is essential that the ionization collected should be limited by the electrodes of the ionization chamber, and that there should be no spurious collection from the space around other components, such as the electrometer valve circuit outside the chamber. The behaviour can be checked by comparing the "apparent" volume of the ionization chamber, as calculated from the measured ionization current using the definition of the roentgen, with the actual or real volume of the chamber. An agreement within about $\pm 5\%$ is good, but a greater departure would mean that some volume outside the ionization chamber is contributing (either in conjunction, or in opposition) to the ionization current. Such a design would give a variable performance as the spurious ionization will not necessarily saturate under the same conditions as the ionization chamber current.

The majority of survey meters have to operate under a wide variety of conditions of humidity, temperature and pressure. It is a big advantage therefore to employ an instrument which is properly sealed. This is difficult, of course, when the instrument involves a beta-window, and provides a strong argument for designing a "gamma-only" instrument, when beta-detection capability can be regarded as a luxury only.

Range of Measurement.—The range of measurement required for these instruments varies according to the application. For geological prospecting the range (expressed in r/hr) is from background to a few hundred micro-roentgens per hour. For health physics 1 mr/hr to 1,000 mr/hr is usually necessary, whereas for radiological defence 0.1 r/hr to 500 r/hr is the generally agreed coverage. In the past multi-range instruments have been employed. For example, in the case of the high-range instrument just referred to, three linear ranges were provided, 0 to 5 r/hr, 0 to 50 r/hr and 0 to 500 r/hr. Clearly high precision is rarely required in these measurements and there are real advantages to be gained by using a single logarithmic scale extending from 0.1 r/hr to 500 r/hr. Range switching is avoided and the instrument can be simpler, and perhaps even more reliable, since fewer components are involved. However, whichever method is adopted the meter scale should be as large as possible with the graduations and numerical values clearly marked.

If range switching is employed, it is a good plan to change the range markings on the scale automatically by means of a mechanical linkage via the range switch.

Measurement of Beta-Radiation.—The provision of a beta-window in a survey meter does no more than make the instrument sensitive to beta-radiation and it does not necessarily follow that the instrument can be used quantitatively.

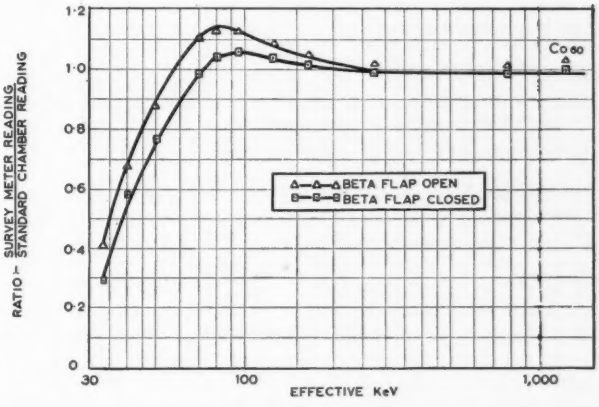


Fig. 6. Energy response characteristics for a survey meter with a beta window.

If the window is limited to one side of the chamber then the meter will exhibit marked directional characteristics. This may not matter for laboratory work but where the instrument is used in connection with a widely distributed source, such as radioactive fall-out, it produces severe limitations. It is recommended that designers of survey meters should measure the directional characteristics of their instruments to beta-radiation and pass this information on to the users.

It is perhaps useful to refer here to some measurements which have been carried out recently at A.E.R.E., to determine the response of a British radiac instrument to beta-radiation. This instrument has a beta-window extending over half the lower face of the case of thickness about 30 milligrams per sq. cm., which is sufficiently thin to allow beta-particles with an energy greater than 0.4 MeV to penetrate into the sensitive volume of the chamber. Measurements were

made with the instrument at a distance of 65 cm. above a semi-infinite flat source first with the survey meter and then with an extrapolation chamber apparatus. This latter allowed a true measurement of the beta-radiation dose to be made. From these results the response of the survey meter was compared with the true dose rate. It was found that with a uniform source of 1 mC/cm^2 the reading of the survey meter was 23.8 r/hr for a Tl 204 source (0.87 (MeV) and 260 r/hr for a Sr 90 source (2.2 MeV). The corresponding readings of "true" dose rate were 810 rad/hr and 2,400 rad/hr giving ratios of 0.03 and 0.01. That is, to determine the true beta dose rate from the measured deflection it is necessary to multiply the observed deflection by a factor varying between 10 and 30 depending on the energy of the radiation.

With mixed fission products the higher ratio can be neglected because of the greater proportion of the very hard beta-radiations (1.5 to 3.5 MeV) which is usually present. It is then reasonable to say that readings taken with the survey meter for an extended fission product source would give a reading of 1/10 of the "true" dose rate. The factor in this case is determined mainly by geometrical considerations rather than absorption effects, but it should be noted that for a survey meter with a smaller window the factor would be larger. It follows that for this particular survey meter a ratio of 10/1 in β/γ dose rate would appear as equal deflections on the instrument. As it is fairly safe to assume that a beta dose of 10 rads is no more serious than a gamma dose of 1 rad, a reasonable impression of the beta-hazard can be obtained. On the basis of the figures given, a beta-hazard comparable with the gamma-hazard would cause a doubling of the deflection on removing the cover plate to expose the beta-window.

In many cases, of course, it is possible to locate and make a measurement of surface contamination in microcuries per sq. cm., but the measurement then becomes the province of the contamination meter.

There are many other considerations which arise in the design of survey meters, for example size and weight, battery life (where batteries are employed), reliability, and so on. These considerations are of the greatest importance, but are outside the scope of the present review.

Accumulated Dosage Meters

The most popular accumulated dosage meter in use at the present time is undoubtedly the so-called quartz-fibre dosimeter, and for convenience it is proposed to limit comments to this type. This comprises a small ionization chamber as the detector component and a quartz-fibre electrometer as the measuring element. They are available in various forms with the "pen dosimeter" the most popular, and can be made to cover ranges from 0 to 100 mr up to 0 to 1,000 r. Dosimeters with ranges of 0 to 500 mr, or 0 to 1.0 r are often employed for health measurements in laboratories and hospitals, where radioactive materials are in use, and where there might be a radiation hazard. Higher range dosimeters are required for radiological defence purposes. These commonly have ranges of 0-50 r, or 0-150 r.

Quartz-fibre dosimeters are almost invariably designed to be sensitive to gamma-radiation only, but a few very specialized instruments have been made which are sensitive tc beta-radiation as well.

Like survey meters, quartz-fibre dosimeters usually need to have a flat sensitivity/energy characteristic extending from about 70 KeV upwards. This can be achieved by using a good air-wall material for the chamber walls and avoiding as far as possible all high atomic number materials. It is necessary that the saturation characteristics of the chamber are such that the sensitivity of the instrument is virtually independent of the dose rate over a relatively wide range. In fact it is possible with quite simple designs of ionization chamber to obtain a good response at dose rates up to about 100 r/sec and 500 r/sec.

The table below gives the saturation characteristics of the chamber and capacitor unit, but excludes the small collecting volume associated with the charging pin.

Fibre Voltage	*Ionization current*		
	100 *r/sec*	500 *r/sec*	0.1 *r/sec*
200	95	88	100
150	92	82	100
100	87	73	100
80	82	68	100

Taking an average fibre swing of 180 V to 100 V for zero to full scale, it is seen that the readings over the entire scale will not be in error by more than about -10% at a dose rate of 100 r/sec and about -22% at 500 r/sec, compared with the calibration at low dose rates.

Instruments of this sort allow surprisingly accurate measurements and for normal health protection, where very high dose rates are not involved a precision of $\pm 15\%$ is fairly easily obtained even with gamma-radiations covering a wide energy spectrum.

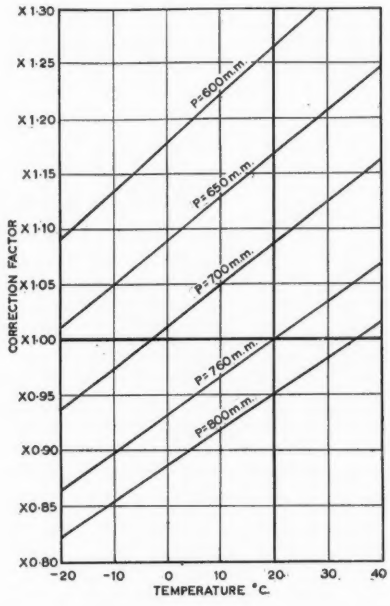


Fig. 7. Correction factor for unsealed ionization chamber with variation of temperature and air pressure.

In practice, it is desirable that the dosimeters should have a very low natural leakage in the absence of radiation and most specifications stipulate a maximum of 2% of full scale in 24 hours for the higher-range instruments.

Another factor to bear in mind is that a substantial overexposure which is sufficient to move the fibre well off scale but not damage the movement, should not impair the insulation characteristics of the dosimeter. This is usually covered in the specification. A further factor to consider is the sealing of the instrument. If it is unsealed then its performance will be markedly dependent on temperature and pressure, because the mass of air in the ionization chamber will vary with these parameters. This is shown in Fig. 7. Most modern instruments tend to be fully sealed to avoid this problem and the practice is to be recommended.

It is also important to remember the directional character-

istics of the dosimeters and the problem of calibration. In use, quartz-fibre dosimeters are normally carried in a vertical position and it is obviously desirable to place them with the ionization chamber at the lower end. The optical system for observing the position of the movement will not then influence the directional characteristics except over a narrow cone in the upper hemisphere, where good omni-directional properties are of least importance.

Charging Units.—Many types of charging units are employed with quartz-fibre dosimeters, but for some purposes there is a real merit in small size. A number of miniature types have been developed, but the most popular, and probably also the most reliable, are likely to be those employing (i) a transistor oscillator operating from a 2.5-V mercury

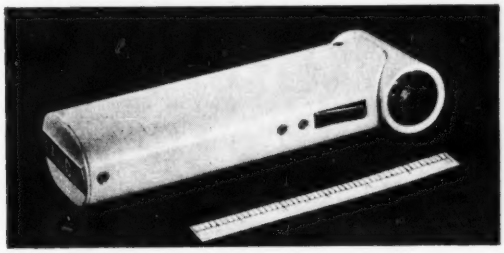


Fig. 8. A transistor charging unit made by R. A. Stephen and Co. Ltd.

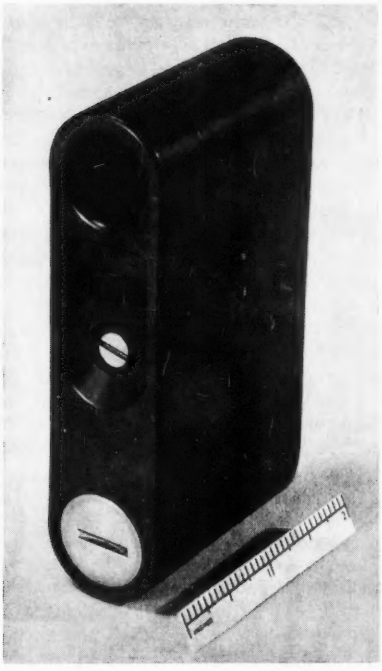


Fig. 9. A Zamboni pile is used on this charging unit made by Dowty Nucleonics Ltd.

cell and giving an output which is rectified to give a D.C. voltage of 300 (the voltage being variable with a potentiometer), and (ii) a Zamboni pile of about 300 V. An example of the first unit is shown in Fig. 8, and an example of the second kind is shown in Fig. 9. It is necessary that consumable components, like the batteries, should have a long life. In the first case the battery should have a life of about two years, whereas a Zamboni pile can have a life of many times this.

Clearly both survey meters and dosimeters may become contaminated, and it is therefore necessary that the external shape and finish of the instrument should be such as to avoid the collection of contamination. Of course, if the instruments have to be used in heavily contaminated areas it is a good plan to use them in plastic bags and destroy the bags after use.

Détecteurs Portatifs de Radiation

Un grand choix est à la disposition d'un fabricant établissant une spécification pour des instruments devant mesurer les radiations. Cependant, les caractéristiques désirables pour un instrument contrôleur de santé, ou de travaux de recherches, ou de défense civile, ne sont pas identiques. Pour les travaux de prospection, une sensibilité de 2π est nécéssaire et la calibration avec un point source peut introduire des erreurs. En même temps, une réponse plate pour une petite angle solide est suffisante pour déterminer la contamination. On rencontre des difficultés quand on a à faire à une grande gamme d'énergies, et la position de l'observateur peut avoir une influence notable. Ceci peut être évité en montant la tête sensible loin de l'opérateur. Des chambres d'ionisation ayant une épaisseur de "mur d'air" entre 1.000 et 1.500 mgm/cm² donnent une réponse plate à partir de 70 KeV. Une caractéristique descendante est préferée pour les faibles énergies. L'insertion d'une hublot mince n'implique pas obligatoirement que l'on puisse faire des mesures quantitatives deβ. Une sensibilité γ/β de 10 à 1 a des avantages. Les compteurs de dosage à fibre de quartz fournissent une solution simple à des problèmes accumulés de mesure de vitesse de dosage. Réference spéciale est faite à deux types de fabrication britannique.

Tragbare Strahlungsmesser

Der Fabrikant, der ein Instrument zur Strahlungsmessung spezifizieren will, hat die Wahl unter einer grossen Zahl von Möglichkeiten. Die wünschenswerten Eigenschaffen einer Instrumentes zur Gesundheitsüberwachung sind jedoch nicht dieselben wie die eines Instrumentes, das zur Erderforschung gebraucht werden soll, und sie suid wieder anders für ein Instrument, das für den Bevölkerungsschutz bestimmt ist. Zur Erkundung von Bodenschichten muss das Instrument nach allen Richtungen im Kreise empfindlich sein (2π) und Kalibrierung mit einer punktförmigen strahlungsquelle Könnte su Irrtümern führen. Zur selben Zeit braucht man eine abgeflaihte Charakteristik über einen kleinen Winkel im Raume, um Messungen über Verseuchungserscheinungen auszuführen. Schwierigkeiten entstehen, wenn die verschiedensten Arten von Energie in Frage kommen, und wenn der Standpunkt des Beobachters eine ausgesprochene Wirkung haben könnte. Dies kann vermieden werden, wenn man den strahlungsempfindlichen Sondenkopf in einiger Entfernung vom Beobachter anbringt. Ionisationskammern mit einem "Luftwall" von einer Stärke von 1000 und 1500 mgm/cm ergeben eine abgeflachte Charakteristik von 70 KeV ab. Eine bei geringer Energie fallende Charakteristik wird vorgezogen. Die Anbringung eines dünnen Fensters schliesst an sich noch nicht ein, dass quantitative β-Messungen gemacht werden können. Eine γ/β Empfindlichkeit von 10/1 ist vorteilhaft. Quarzfaserdosis mengenmesser ergebeu cine einfache Lösung des Problems des Akkumulierungsverhältnisses. Es wird speziell auf zwei britische Instrumente hingewiesen, die fabrikmässig hergestellt werden.

Aparatos Portátiles de Supervisión de Radiación

Hay disponible una gran variedad de selección para el fabricante al preparar una especificación para un instrumento de medición de radiación. Con todo, las características deseables de un instrumento para supervisión sanitaria, trabajo de reconocimiento y defensa civil no son idénticas. Para labores de reconocimiento es necesaria una sensibilidad 2π y la calibración con un punto de origen puede introducir errores. Al mismo tiempo, una respuesta plana sobre un ángulo pequeño sólido es adecuada para trabajo de contaminación. Las dificultades surgen cuando se tiene que hacer frente a una serie ámplia de energías, y la posición del observador es capaz de ejercer un efecto marcado. Este contratiempo puede ser evitado montando la cabeza sensible a distancia del operador. Las cámaras de ionización con un "muro de aire" de espesor de entre 1000 y 1500 mgm/cm² dan una respuesta plana desde 70 KeV para arriba. Es preferible una característica caediza en las energías bajas. La inclusión de una ventana de poco espesor no implica que necesariamente puedan hacerse mediciones cuantitativas β. Una sensibilidad γ/β de 10/1 posee ventajas. Los dosímetros de fibra de cuarzo ofrecen una solución sencilla a los problemas de la razón de dosificación. Se hace referencia especial a dos tipos de manufactura británica.

The Structure of the Atomic Energy Authority

Responsibilty for atomic energy developments in the United Kingdom has been vested in the Atomic Energy Authority. This committee is more commonly termed the board whilst the word authority is frequently used to denote the whole organization. A brief analysis of its structure cannot explain all its ramifications but a broad picture can be given.

THE responsibility for the development of nuclear energy in Great Britain was transferred from the Ministry of Supply to an independent authority on August 1, 1954. Prior to that time the Ministry of Supply began to take over from D.S.I.R. in November, 1945, coincident with the announcement that Harwell had been chosen as the site for atomic energy research work. During the following years six other establishments had been set up over the country and the atomic energy work had been divided into three main groups.

The Atomic Energy Executive comprises five permanent members who, with five part-time members and presided over by a chairman, make up the Atomic Energy Authority. The Board, as it is often loosely termed, is appointed by the Lord President of the Council as the minister responsible to Parliament, but at the present moment information is given via the Lord Privy Seal, Mr. Butler. Permanent members of the Board include the directors of the three groups, a member for finance and administration, and a member responsible for collaboration with overseas countries and industry. The five part-time members represent the interests of industry the trade unions, the universities and the electricity supply.

The three groups are as follows:

1. The Industrial group with headquarters at Risley—director, Sir Christopher Hinton;
2. Research group with headquarters at Harwell—director, Sir John Cockcroft;
3. Weapons group with headquarters at Aldermaston—director, Sir William Penney.

There is also a London Office answering directly to the Board. This office is responsible for general administration, security, metals, finance and legal aspects as well as collaboration with industry and overseas, and public relations. A limited amount of contract work, particularly imports, is handled by London.

The Industrial Group

The Industrial Group is in charge of the design, construction and commissioning of all nuclear plant for the production and separation of fissile material, for prototype power-reactors and for the large-scale separation and disposal of fission products. At present the operation of these plants and the experimental power reactors will be controlled from Risley; reactors and power stations built or bought by industry and the C.E.A. will be operated by their own personnel. It is probable that for many years to come the processing of irradiated fuel will be handled by the Authority but the preparation of basic materials and components can be expected to move more and more into the hands of industry.

The work of the Industrial Group has been divided into three main categories: engineering; operations; and research and development.

Specifically the engineering division is responsible for the various projects of design and construction; that is, for converting experimental data into "hardware." It can be again broadly subdivided into two sections covering reactors for civil use, like the Calder Hall type, and experimental reactors such as Dounreay. This should not be taken as indicating confinement to these two fields only, as many of the ancillary offices come under its direction; contracts is one example.

The operations division is now responsible for the running of the production establishments such as Windscale and Capenhurst and is preparing for the operation of the first power stations. The terms of reference of this division are probably more readily definable than any other.

The research and development division is composed of three departments dealing with metallurgy, chemical engineering and physics and experimental engineering. The work undertaken by this division is similar in some respects to the work at Harwell, but the broad distinction can be drawn that the research and development branch of the Industrial Group is largely concerned with the immediate problems of the design and operational divisions, leaving the longer-term experimentation to the Research Group. Certain aspects of heavy engineering research however are carried out by the Industrial Group because of its greater facilities. In order to take full advantage of the experience gained and the plant available at the various production establishments, individual research and development groups have been set up on the premises.

Apart from headquarters the only research and development group not directly associated with an operational works is at Culcheth where much of the metallurgical experimentation is carried on. When progress in this particular field is beyond the laboratory stage the project is transferred to a works with the appropriate background. Springfields, the site for which was first chosen in early 1946, and where the uranium ore is processed, has largely been concerned with the manufacture of reactor fuel elements.

The plutonium production plant built at Sellafield and now known as the Windscale Works has accumulated a considerable amount of experience in the construction and operation of plants handling radioactive materials. Furthermore, operation of the two reactors on this site has provided additional information on the problems associated with graphite-moderated gas-cooled natural uranium reactors.

The gaseous-diffusion plant at Capenhurst for the enrichment of uranium in U 235 has entailed much development of large-scale mechanical and chemical engineering plant and a large proportion of research and development work has been done here.

An experimental establishment has been set up at the Dounreay Works where the mechanics of breeding and the operating of compact high-power reactors can be studied. In addition to the fast reactor now under construction, a heavy-water reactor similar to PLUTO is planned and space is available for further installations. It is expected that at least three other experimental power stations will be built on the site.

The Research Group

As the oldest establishment in this country dealing with atomic energy, Harwell has been the source of the majority of experimental work. As already stated the chief distinction between the activities of the research and development branch of the Industrial Group and A.E.R.E. lies in the scale of engineering involved in a particular project and the breadth of application of the research.

The establishment is divided into 12 technical divisions, the functions of which are self-explanatory. They are as follows: nuclear physics; general physics; theoretical physics; health physics; reactor division; metallurgy; engineering services; chemistry; chemical engineering; electronics; isotopes and extra-mural research. Recently some integration has taken place between the divisions with the formation of design

project teams. Also located on the Harwell site is a branch of the Medical Research Council. In addition, the Radiochemical Centre, Amersham—originally operated for the Ministry of Supply by Thorium Limited—became an outstation in 1950. The isotope division is to be further expanded by the setting-up of a technological irradiations branch at Grove Airfield, near Wantage.

Within the past few weeks an announcement has been made that further extension of the works at Harwell would be discontinued and a new site would be selected. The main function of this new station is believed to be experimental reactor construction. A possible choice of site is near Wareham, in Dorset.

A subsidiary workshop unit has been established at Bracknell in Berkshire.

The Weapons Group

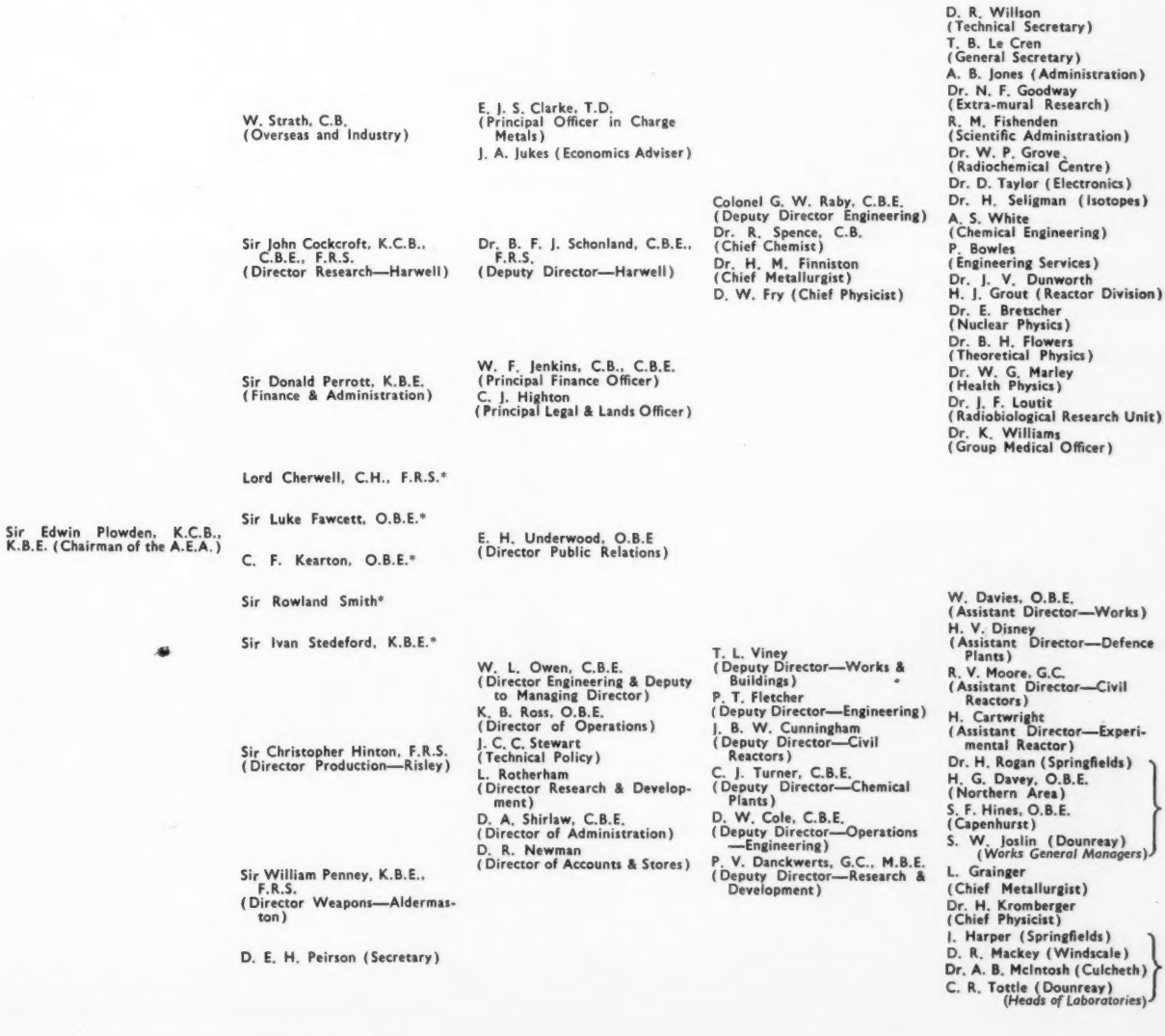
It is not proposed to deal in detail with the construction of the Weapons Group, but clearly it is responsible for the supply of nuclear weapons to the Ministry of Supply who in turn are the operative body for equipping the armed forces.

It remains to be seen how much of the results of the considerable research work at Aldermaston will be made available to industry and to other establishments but no doubt the governing considerations will be those of international politics.

London Office

Whereas individual groups and, to a certain extent, establishments are responsible for their own buying and contract work, the Director of Contracts attached to the London Office is answerable for the efficiency and observance of correct procedure. The procurement of certain basic materials, such as uranium, is handled by the London Office metal branch.

Certain aspects of the Atomic Energy Authority's duties are difficult to define, particularly with regard to developments and projects outside the groups. By the Atomic Energy Acts of 1946 and 1954 the Authority is the only body allowed to own or delegate ownership of fissile materials, but must of course work in close co-operation not only with industry but with Ministries and the Government. The extent of its specific controlling power in some instances requires clarification but in such a fast-moving industry, as nuclear engineering is bound to be at the present stage, a large measure of flexibility is desirable.


Sir Edwin Plowden, K.C.B., K.B.E. (Chairman of the A.E.A.)
W. Strath, C.B. (Overseas and Industry)
Sir John Cockcroft, K.C.B., C.B.E., F.R.S. (Director Research—Harwell)
Sir Donald Perrott, K.B.E. (Finance & Administration)
Lord Cherwell, C.H., F.R.S.*
Sir Luke Fawcett, O.B.E.*
C. F. Kearton, O.B.E.*
Sir Rowland Smith*
Sir Ivan Stedeford, K.B.E.*
Sir Christopher Hinton, F.R.S. (Director Production—Risley)
Sir William Penney, K.B.E., F.R.S. (Director Weapons—Aldermaston)
D. E. H. Peirson (Secretary)
E. J. S. Clarke, T.D. (Principal Officer in Charge Metals)
J. A. Jukes (Economics Adviser)
Dr. B. F. J. Schonland, C.B.E., F.R.S. (Deputy Director—Harwell)
W. F. Jenkins, C.B., C.B.E. (Principal Finance Officer)
C. J. Highton (Principal Legal & Lands Officer)
E. H. Underwood, O.B.E (Director Public Relations)
W. L. Owen, C.B.E. (Director Engineering & Deputy to Managing Director)
K. B. Ross, O.B.E. (Director of Operations)
J. C. C. Stewart (Technical Policy)
L. Rotherham (Director Research & Development)
D. A. Shirlaw, C.B.E. (Director of Administration)
D. R. Newman (Director of Accounts & Stores)
Colonel G. W. Raby, C.B.E. (Deputy Director Engineering)
Dr. R. Spence, C.B. (Chief Chemist)
Dr. H. M. Finniston (Chief Metallurgist)
D. W. Fry (Chief Physicist)
T. L. Viney (Deputy Director—Works & Buildings)
P. T. Fletcher (Deputy Director—Engineering)
J. B. W. Cunningham (Deputy Director—Civil Reactors)
C. J. Turner, C.B.E. (Deputy Director—Chemical Plants)
D. W. Cole, C.B.E. (Deputy Director—Operations—Engineering)
P. V. Danckwerts, G.C., M.B.E. (Deputy Director—Research & Development)
D. R. Willson (Technical Secretary)
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A. B. Jones (Administration)
Dr. N. F. Goodway (Extra-mural Research)
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Dr. D. Taylor (Electronics)
Dr. H. Seligman (Isotopes)
A. S. White (Chemical Engineering)
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H. J. Grout (Reactor Division)
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Dr. W. G. Marley (Health Physics)
Dr. J. F. Loutit (Radiobiological Research Unit)
Dr. K. Williams (Group Medical Officer)
W. Davies, O.B.E. (Assistant Director—Works)
H. V. Disney (Assistant Director—Defence Plants)
R. V. Moore, G.C. (Assistant Director—Civil Reactors)
H. Cartwright (Assistant Director—Experimental Reactor)
Dr. H. Rogan (Springfields)
H. G. Davey, O.B.E. (Northern Area)
S. F. Hines, O.B.E. (Capenhurst)
S. W. Joslin (Dounreay)
(Works General Managers)
L. Grainger (Chief Metallurgist)
Dr. H. Kromberger (Chief Physicist)
I. Harper (Springfields)
D. R. Mackey (Windscale)
Dr. A. B. McIntosh (Culcheth)
C. R. Tottle (Dounreay)
(Heads of Laboratories)

* *PART-TIME MEMBERS*

Reactors and Power Production at Marcoule

The three reactors at Marcoule are now designed to generate electric power as well as produce plutonium. Details of the G1 and G2 piles with central entry cooling are given with a brief description of the plutonium-production plant.

IN the 1952 French five-year nuclear power programme, the first piles, G1 and G2, were planned to serve only for the production of plutonium for future Electricité de France power stations. It was intended, therefore, that the plant established at Marcoule should be completed by a factory for the extraction of plutonium, but it has now been decided that energy should be recovered from the plutonium-producing piles themselves. For G1 the output will be only 5,000 kW but with G2 and G3 it is hoped to attain a net power output of 20,000 kW from 100,000 kW of heat generated.

G1

The fuel used in G1 is natural uranium with graphite as the moderator and air at approximately atmospheric pressure as the coolant. The total thermal output of the reactor is 40 MW. The charge of 100 tonnes of natural uranium, sheathed with magnesium, and consisting of cartridges 3.80 m. long, is in bars 100 m. long and 26 mm. diameter. The profile of the sheath has eight fins, the over-all diameter being 62 mm. whilst the diameter of the channels pierced in the graphite is 70 mm. The graphite pile, roughly cylindrical in shape, with a length of 8.840 m. and a diameter of 9.600 m. (with a reflector of 0.660 m.) has a gap of 80 mm. width cutting across the central section. It is pierced by 1,337 horizontal channels in each half pile.

The cooling air is drawn in through a chimney 25 m. high, and passes through intake filters. The blowers, located between the filters and the reactor, are each driven by a 2,600-kW 5,500-V motor, and have an output of 80 m^3/sec. at a pressure of 2,500 mm. of water. Before entering the pile the air passes through cooling towers which reduce the air temperature at the entrance to the reactor to 18° C. A duct then takes the cooling air to the central gap provided in the reactor.

The air leaving the reactor passes through an air-water heat exchanger with the following characteristics:

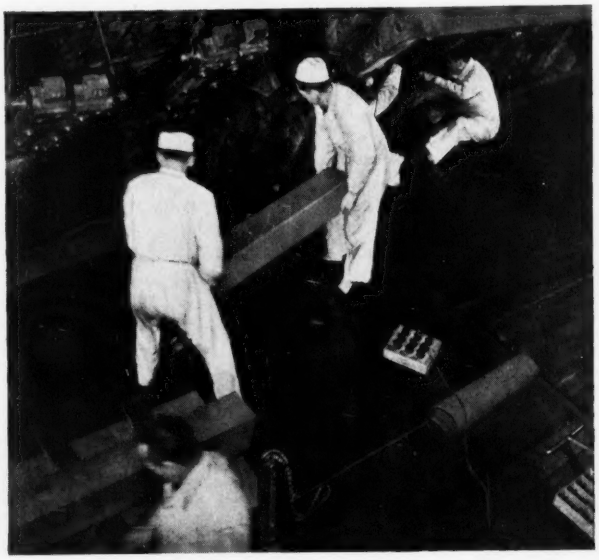
Surface of heat exchanger		58,000 m^2
Gas (air)	Inlet temperature	220° C.
	Outlet temperature	80° C.
	Delivery	257 kg/sec.
	Inlet pressure	300 kg/m^2
	Mean velocity through exchanger	6.95 m/sec.
Water	Inlet temperature	60° C.
	Outlet temperature	200° C.
	Delivery	61 kg/sec.
	Inlet pressure	20 kg/cm^2
	Velocity of water	1.18 m/sec.

The heat exchanged can be 31,500,000 k.cal/hr. with a wall loss of 315,000 k.cal/hr. the efficiency being 99%.

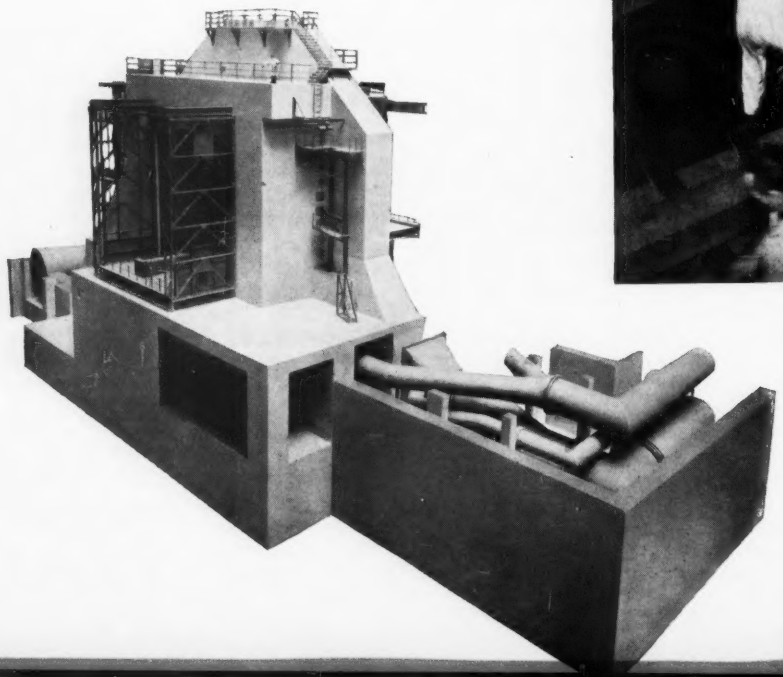
The water heated in the exchanger is delivered into flash boilers, the steam being led to a vertical Rateau turbine running at 3,000 r.p.m. and coupled to a 5,750-kW, 550-V Alsthom alternator.

G2

In G2 the pile uses natural uranium as fuel, graphite as the moderator and CO_2 under pressure as the coolant. The project is a result of studies carried out in collaboration by (a) Le



A stage in the building of G1. The graphite blocks are stacked with great precision under conditions of extreme cleanliness.



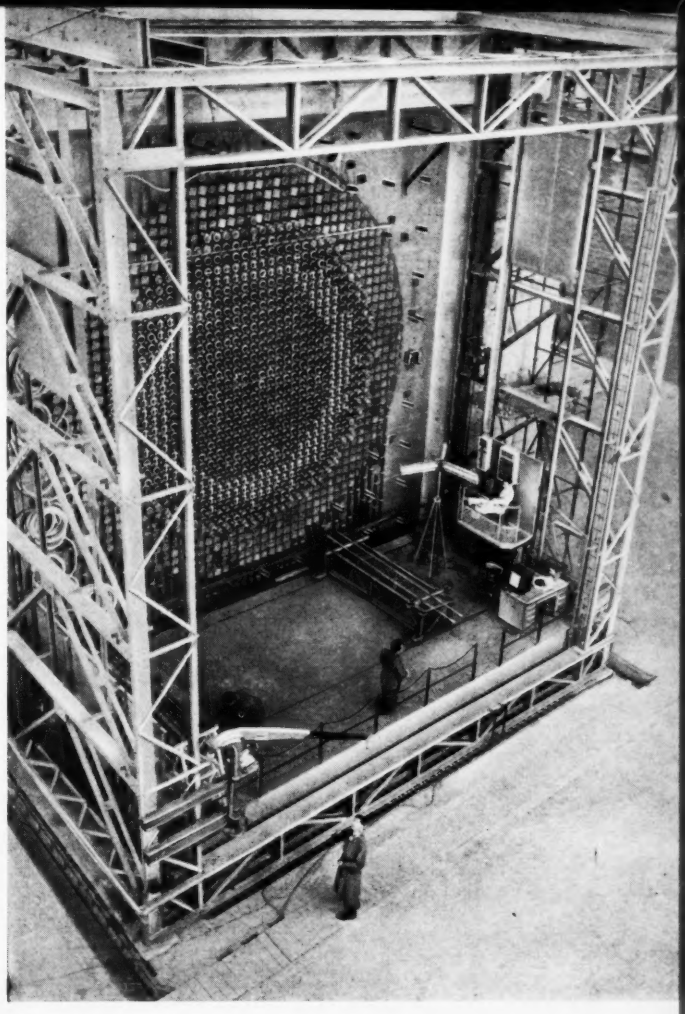
(Left). A model of G1 showing the air ducts and general form of construction for central entry cooling.

Commissariat à l'Energie Atomique (Départment d'Etudes de Piles); (b) Electricité de France (Nuclear Equipment Section) and (c) French Industry—Société Alsacienne de Constructions Mécanique, Société des Forges et Ateliers du Creusot, Société Rateau et Alsthom.

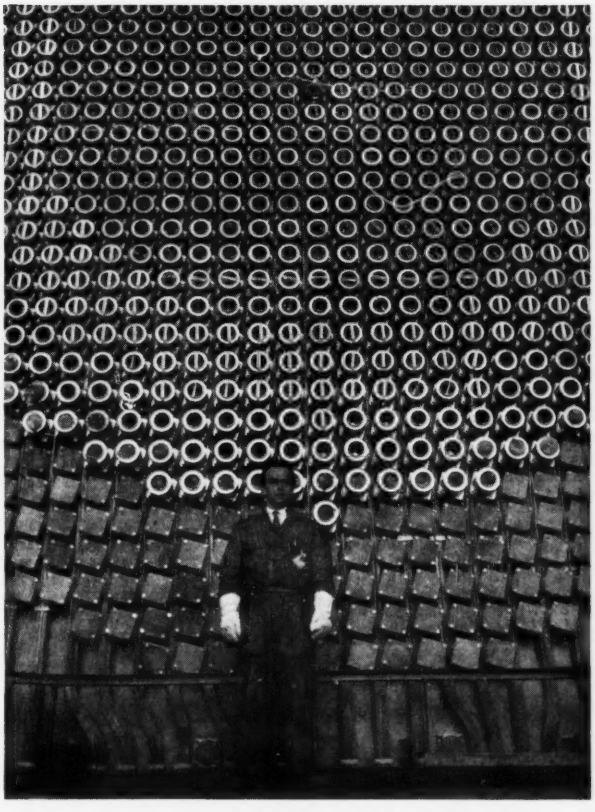
The fuel (100 tonnes of uranium) is in the form of cylindrical elements 26 mm. in diameter and 300 mm. long, consisting of an alloy of natural uranium and a very small proportion of aluminium. Each element is sheathed in a thin magnesium can to which it is mechanically bonded. These fuel elements lie in 70-mm. channels cut horizontally in the graphite which has a density of 1.70 and an effective capture cross-section of 4 mb. It is in the form of blocks of square section, the sides (200 mm.) being of the same dimension as the pitch of the lattice which is also square. The blocks of graphite are built up to form a prism with a vertical bisecting plane. Outside the active core (height: 8.45 m., diameter: 7.80 m.), corresponding to 1,200 channels—there is a lateral peripheral reflector of 0.500 m. section. Under these conditions, the available reactivity, after allowing for the reserve needed for temperature effects and fission-product poisoning, is sufficient to permit an additional production of uranium 233 from thorium, the use of slightly depleted uranium, a flattening of neutron flux, or combinations of all three factors.

The arrangements for control and safety are similar to those in BEPO. The renewal of fuel can be carried out without the necessity of shutting down the pile.

The gases coming from the three sections of the reactor mix at the delivery side at an average temperature of about 300° C. By tapping off some of the hotter gases from the periphery of the pile the steam may be superheated. This steam is generated in heat exchangers, and delivered to turbines of normal design, driving an alternator and CO_2 compressors. A small auxiliary boiler is necessary for starting up the plant which, at full power, has an output of 30,000 kW.



Load face of G1. The general appearance, as would be expected with a graphite-moderated gas-cooled reactor, is similar to BEPO.



Close-up of the load face of G1.

The reactor core, the devices for renewing the fuel and the thermal insulation must be enclosed in a gas-tight pressure vessel pierced by a large number of holes. The construction of a cylindrical steel vessel with a diameter of 10 m. such as would be required presents many problems and it was decided to build it in concrete. Instead of the standard reinforced concrete system which did not appear to be suitable, pre-stressed concrete is used, the strength of the cylindrical shell being provided by the pre-stressing which also plays a part in the stability of the foundations. The concrete structure has an interior lining of steel plate.

Plutonium Production

Marcoule is a station for the production of plutonium. Irradiated uranium bars from all the reactors under construction on the Marcoule site, namely G1, G2 and G3, will be treated. The building for the treatment of the bars forms a block 170 m. long, 37 m. wide and 17 m. high. In all, more than 14,000 $m.^3$ of concrete and 3,400 tons of lead will be necessary.

The plant is divided into four zones:

(1) An active zone in which is located the main equipment for the treatment and to which access is forbidden;

(2) A semi-active zone which the operating personnel will be able to enter periodically, to carry out certain operations for verification and maintenance of the control equipment or take samples;

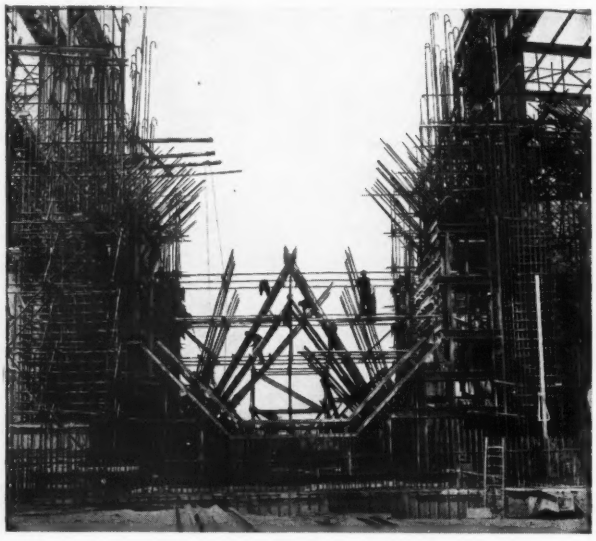
(3) An inactive zone comprising passages for the inspection of the active zone and the compartments for the final recovery of the slightly contaminated uranium;

(4) A working zone in which the final operations for the purification of the plutonium and the withdrawal of the metal will be carried out.

These zones are maintained at different pressures by a fan system which allows up to eight renewals of the atmosphere per hour.

Four months after the mechanical unsheathing, the uranium bars, in their stainless-steel containers, are taken to the factory and are placed in a descaling bath in which the last traces of magnesium are removed from the uranium by washing in dilute nitric acid.

The containers are then plunged into the dissolver in which the uranium is attacked by hot concentrated nitric acid. Up



G1 under construction. Reinforcing for the biological shield at the two sides is nearing completion and work has begun on the main core structure.

to the final phases, the operations are now carried out with liquids which are transferred without pumps by siphoning or gravity circulation.

The extraction operations allowing the separation of the various constituents of the initial solution are effected in batteries of mixer-settlers in which the solution to be extracted and the extracting liquid circulate in counter current flow; the delivery from a settler to the next mixer is carried out by the impeller which draws in the liquids to be pumped from the two adjacent settlers.

The aqueous phase arising from the extraction contains neither plutonium nor uranium, but it comprises all the fission products and the magnesium, nitric acid, and so on. In view of its radioactivity—of the order of some dozens of curies per litre—the only possibility is to store it. It is, nevertheless, desirable to limit its volume; this is the purpose of the evaporators which, in groups of two, concentrate the solution and reduce its volume to one-hundredth of what it was originally.

The plutonium solution resulting from the extraction is concentrated by a soda precipitation, the precipitate being redissolved in nitric acid. The final decontamination of the plutonium solution is carried out by the normal process of extraction of the solvent, followed by purification on resin and an oxalate precipitation. The purified plutonium oxalate is then converted into ingots of metal.

The large quantities of oxalate resulting from the extraction process have to be put in a form such that the storage shall be relatively easy. The uranyl nitrate is first precipitated by oxalic acid and then the oxalate is washed to put the finishing touch to decontamination. There is a second decantation, the precipitate is dried in a steam-heated rotary drier and the uranium oxalate is placed in drums pending its transformation into metal.

Control of the atmospheric air is carried out locally at each point where the risk (although slight) of contamination is possible and the indications of danger are recorded in the control room by alarm devices. In this room are centralized all the instruments indicating output, levels, temperatures and pressures, on a large board 50 metres long, where graphic recording instruments for the essential circuits allow the operation of the plant at least the active part, to be conveniently followed. The personnel necessary for the operation of the factory will be of the order of 60 workmen and specialist engineers.

Les Réacteurs et la Production Electrique à Marcoule

On a décidé d'utiliser les réacteurs de Marcoule comme générateur d'électricité. G1 aura un rendement limité de 5.000 k.w., mais G2 et G3 sont prévus pour produire 20.000 k.w. d'électricité avec un rendement de 20% G1 et G2 sont tous deux des réacteurs à refroidissement à gaz avec entrée centrale, utilisant de l'uranium naturel modéré au graphite, ayant leurs éléments combustibles enclos dans du magnésium. G1 est refroidi par air tandis que G2 a un refroidissement par le CO_2. Dans les deux cas le chargement initial de combustible est de 100 tonnes. A cause du grand nombre de trous qui le transpercent, le récipient contenant est en béton contraint. L'installation de production de plutonium est divisée en quatre zones pourvues de système de ventilation indépendant. L'extraction se fait par un système mélangeur-sédimenteur, et les solutions actives contenant la majorité des produits de fission sont concentrées par évaporation et ensuite emmagasinées. Le métal plutonium se prépare finalement à partir de l'oxalate. Une chambre de contrôle centrale permet le contrôle permanent de tout le procédé.

Reaktoren und Krafterzeugung in Marcoule

Es ist der Beschluss gefasst worden, mit den Reaktoren in Marcoule Elektrizität zu erzeugen. G1 soll nur eine begrenzte Leistung von 500 kW haben, G2 and G3 jedoch sollen nach dem Plan 20,000 kW elektrische Energie mit einem Wirkungsgrad von 20% produzieren. Beide, G1 und G2 sind Reaktoren, die mit natürlichem Uranium mit Graphit als Moderator arbeiten, mit zentraler gasgekühlter Zuführung und mit Brennstoffelementen in Magnesiumkapseln. G1 ist luftgekühlt, während G2 mit CO_2 gekühlt werden soll. In beiden Fällen ist die Angangsscharge 100 t. Wegen der grossen Zahl von Bohrungen ist der Behälter aus Spannbeton konstruiert. Das Werk, das das Plutonium erzeugt, ist in vier Zonen aufgeteilt mit unabhängigen Ventilierungseinrichtungen. Die Extraktion wird mittels Gemischfällverfahrens durchgeführt und die aktiven Lösungen, die den grössten Teil der Spaltprodukte enthalten, werden durch Verdampfung konzentriert and dann gelagert. Das Metall Plutonium wird als Endprodukt from Oxalat gewonnen. Ein Zentralkontrollraum gestattet fortlaufende Ueberwachung des ganzen Prozesses.

Reactores y Producción de Energía en Marcoule

Se ha decidido generar electricidad de los reactores en Marcoule. G1 tendrá un rendimiento limitado de 5.000 k.w., pero G2 and G3 han sido ideados para producir 20.000 k.w. de energía eléctrica a una eficiencia del 20%. Tanto G1 como G2 son reactores de uranio natural, moderados a grafito, y enfriados con gas de admisión central, con los elementos combustibles forrados en magnesio. G1 es de enfriamiento por aire, mientras que G2 va a ser enfriado con CO_2. En ambos casos la cargoa inicial de combustile es de 100 toneladas métricas. Debido al gran número de agujeros de perforado, el recipiente de alojamiento ha sido construído de hormigón pretensado. La planta de producción de plutonio está dividida en cuatro zonas con sistemas independientes de ventilación. La extracción se lleva a cabo con un sistema mezclador-separador y las soluciones activas que contienen la mayor parte de los productos de fisión son concentradas por evaporación, almacenándose luego. El metal plutónico se prepara finalmente del oxalato. Una sala de control centralizada permite el control de todo el procedimiento.

Fission Product Disposal from Windscale

Experiments were made on the dispersal effects of tide and wind on bulk dumpings of fluorescein in the sea followed by investigations into concentration characteristics of silt, seaweed and fish, before the low activity effluent was discharged into the sea at Windscale. Several years continuous disposal by this technique proves that initial estimates erred on the side of safety.

by

P. V. DANCKWERTS, M.A., S.M., G.C., M.B.E.

Deputy Director, Research and Development, Industrial Group, A.E.A., Risley

THE disposal of fission products, resulting from the operation of the first British plutonium-producing piles and associated chemical plant, at Windscale, Cumberland, was a problem offering considerable difficulties. Whilst the main bulk of the fission products could be stored in tanks, in the form of a concentrated solution, there remained a relatively large volume of effluent of very low specific activity, arising from certain plant operations, laboratory drains, laundries, etc., which would be excessively expensive to store. It was decided to make use of the most straightforward and convenient method of disposal on a small and densely populated island and discharge it straight into the sea. Alternative ground disposal methods did not give, it was felt, a sufficient certainty of containment, and concentration by ion-exchange was rejected on technical and economic grounds. It should be emphasized that the activity to be discharged into the sea constitutes only a minute fraction of the throughput of the chemical plant.

Up to 10,000 gallons of effluent a day was expected to be handled, containing approximately 100 curies of fission products. Discharge was to be by a pipeline taken out over the sea bed for an adequate distance. Before plans could be finalized data were required on the maximum permissible rate of discharge of the various radioactive elements, and the distance out to sea that the pipe should be taken. In the absence of any information about the fate of fission products discharged into the sea, and the disposal of effluent by water movement, experiments were started to find the answers.

A study was therefore made of the influence of tide and wind on the movement and dispersal of effluent discharged into the sea at various distances from the shore. The green dye fluorescein was known to be suitable as a tracer medium, in that its concentration can be measured down to very low levels by means of its fluorescence in ultra-violet light. The method adopted was to dump 10-ton batches of fluorescein solution into the sea, and to follow the position and spread of the patches with three vessels equipped with sampling booms enabling them to pump up sea water continuously from depths of one, six and twelve feet. The positions of the vessels were plotted by shore-based radar. The concentration contours of the patches were determined, each patch being followed for 10-15 hours.

In the absence of wind, the centre of the patch was not found to move progressively, although it spread continuously, but merely back and forth with the tide, a few miles on each side of the point of discharge, and parallel to the coast. The spreading and dispersal of the patch was due to the turbulent flow of the water, fraying away the edges of the patch, and the difference in tidal speed between the surface and the sea-bed. This "shearing" action is shown in Fig. 1. Eddies cause vertical mixing — quite rapidly in shallow water—so that when the tracer is dumped a column is formed between the seabed and the surface (A). Since the tide flows fastest near the top the column would begin to lean sideways were there no vertical mixing (B). However, as the arrows suggest, the tracer is spread evenly between top and bottom by the mixing, resulting in the smearing out (C) of the patch in the direction of the flow, whilst its centre moves downstream (D, E). The combination of eddy and shearing flow spreads the patch out into a thin eclipse, which moves up and down the coast, spreading all the time. Thus a strong tidal movement, even if it is purely oscillatory, is a great help in dispersing the effluent.

As a result of the quantitative information gained from the single discharges, predictions could be made for the effect of a regular succession of discharges made at a fixed point off the coast. As long as there is a wind, the resulting current carries away the effluent, diluting it as it goes. In calm weather successive discharges will accumulate, the concentration round the pipeline increasing steadily. From the experiments it was possible to calculate the concentrations in calm weather, in terms of rate of discharge and length of pipeline. The concentration at the waterline was of special importance because of possible hazards to people on the beaches, and the harvesting of edible seaweed. Assuming 50 successive calm days—a most unlikely occurrence—it was estimated that the daily discharge of 100 curies from a pipeline 2 miles long would produce a maximum concentration of about 10^{-4} micro-curies per litre at the waterline.

When the actual pipeline had been installed, further experiments were carried out, fresh water being used to simulate the density of the effluent. The proposed operational procedure for discharge was followed: several hundred cubic metres of water being put out during a period of an hour or so after high water. These experiments gave some information about the dilution of the effluent during its rise through some 60 ft. of seawater. Whilst in calm weather this initial dilution is only a few hundred fold, in normal weather, with winds of 10 m.p.h. and more, and corresponding seas, the dilution is several thousand.

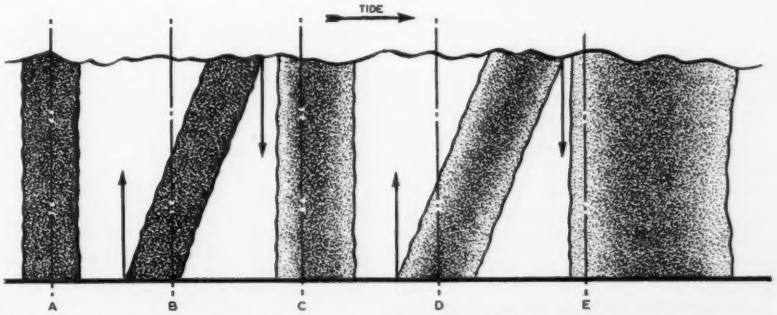


Fig. 1. Representation of the effect of turbulence and tide on effluent dispersion.

Next came the question of the maximum permissible level of concentration in the sea of the various radioactive elements likely to be present in the effluent. In solution, it must be emphasized, these substances are most unlikely to give rise to hazards, because factory effluent is so dilute that a further dilution factor of 10,000 would bring the concentration of all radioactive substances down to levels permissible in drinking water. Such dilution normally occurs within a short distance of the outlet of the pipeline. Unfortunately the radioactive elements may be concentrated by adsorption on the sea-bed, or assimilation by fish and seaweed. It was therefore necessary to measure in each case the concentration factor, that is the ratio of concentration in the solid to that in the sea.

Sea-bed concentration is mainly of interest between low and high water marks, where a radiation hazard could exist for people on the beach, although trawler gear contamination has also to be considered. Experiments showed that the major concentration was effected by very small particles of silt; the sea-bed activity was likely to increase in calm weather when the silt settled out. Allowing for this, the concentration factors adopted were 1,000 for yttrium, cerium, and the rare earths, 100 for ruthenium and caesium, and 10 for strontium.

By marking plaice, the main commercial fish on this coast, it was found that those caught in the vicinity might have spent several months there, so that it could be assumed that they had reached equilibrium with radioactivity in the sea. Concentration factors were determined by keeping fish in tanks of seawater containing small concentrations of the various compounds and subsequently measuring the concentrations in the fish-flesh. As a result, concentration factors were found to be fairly low, the highest being 12 for cerium. That for plutonium was guessed to be about 50, but has subsequently been shown to be about one.

The Cumberland coast is unfortunately one of the few areas in England where edible seaweed is gathered to make a Welsh delicacy, laver bread. Concentration factors in this seaweed are inclined to be high, being of the order of a few hundred for yttrium, cerium, ruthenium and plutonium. The seaweed grows only between low and high water lines.

The relationship between concentration in the sea, fish, seaweed and sea-bed now established, it was necessary to lay down the maximum permissible levels of activity in these materials compatible with public safety. It was decided that these levels should be such that no member of the public could conceivably be exposed to more than one-tenth of the occupational activity levels recommended by the International Commission on Radiological Protection. At the same time the assumptions made about the time spent on the beach, and the amount of fish and seaweed eaten, were such that very few people would approach this limiting exposure, and the great majority of those who might be exposed would receive negligible levels of radiation. Since the original estimates were made, experiment, experience and changes in the internationally agreed standards have led to some relaxation (Fig. 2).

Material	Max. Level of Activity	Safety Margin
Shore sand:	25×10^{-3} μc/gm.	Any individual could safely spend 100 hours a year on the beach.
Sea bed:	10^{-1} μc/gm.	It has been shown experimentally that trawling gear can be safely handled after contact with the sea bed.
Fish-flesh:	Ten times m.p.l. for any radio-isotope in drinking water.	If this is maximum level of contamination, average level throughout fishing ground is safe by substantial margin.
Edible seaweed:	Ten times m.p.l. for any radio-isotope in drinking water.	If this is maximum level of contamination, average level throughout harvesting ground is safe by substantial margin.

Fig. 2. Table of maximum levels of activity in the significant concentrating media, correlated with the hazards they represent.

The steps in the calculation may be summarised as follows: estimates of exposure on the beach and consumption of contaminated fish and seaweed led to the definition of maximum permissible levels of activity in these substances. The concentration experiments enabled these to be translated into maximum permissible concentrations in the sea-water. The tracer experiments made it possible to calculate, for a given length of pipeline, the maximum rate of discharge compatible with these concentrations.

Considerable uncertainties were involved at each step, and the figures used in each case were conservative. Nevertheless, in making the final recommendations an overriding safety factor of 10 was applied.

It was decided to run two pipelines each 10 in. diameter 2 miles out beyond the high-water line, the distance between the chemical processing area and the high-water line being $\frac{1}{2}$ mile. The gradient of the bed of the sea is about 1 in 100, the bottom mainly sand with a few stony patches. The pipes were laid by dragging them out over the sea-bed, a technique previously used in laying pipelines for loading and unloading tankers.

Pipe weight was reduced by keeping it full of air, a sledge being fitted to the seaward end so that it would ride over hummocks in the sea-bed. A runway was prepared for the pipe which consisted of a series of skids set into the beach between low and high water marks. Above the high-water line the pipe lay on a series of trollies running on rails. Lack of space in the hinterland limited the ready-made length of pipe to $\frac{1}{2}$ mile, and halts had to be made in the pull so that sections could be welded together. The preparatory work took 18 months, but the actual laying of each line was accomplished on one tide, by a 12,000-ton tanker guided by three tugs.

The project, completed in 1950, cost £300,000, and this would have been lower by a third had it not been necessary to carry the inshore runway over a mainline railway, a river, and other obstacles (Fig. 3).

As soon as fission products became available from the plant it was possible to start a continuous programme of experimental discharges to verify the estimates previously made. The results

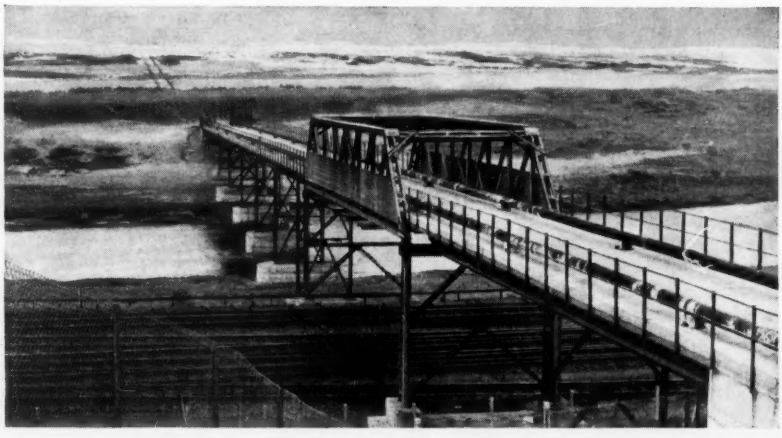


Fig. 3. The two effluent pipelines, crossing the railway and river. View looking seaward.

of these tests were satisfactory, and in fact led to some relaxation of the limits on the rate of discharge. Low activity effluent has now been discharged into the sea as a matter of routine for several years. The following table (Fig. 4), which has been averaged over many months, gives an indication of current discharge rates and activity levels. The latter show no further tendency to rise.

In the worst case (β ray emitters in seaweed) the activity is only 1/10 of the maximum permissible level. It will be seen that contamination of shore and sea-bed is not a limiting factor; the discharge of plutonium is limited by the contamination of fish but in all other cases the limiting factor is set by the contamination of seaweed, a somewhat unusual complication.

Nuclides	Mean daily Discharge (curies)	Nature of Sample	Mean Activity of Sample (μc/gm)	Assumed Criterion of Safety (μc/gm)
Plutonium 239	0.05	Fish	4×10^{-7}	3×10^{-5}
		Seaweed	3×10^{-8}	3×10^{-5}
Strontium 90	7	Fish	2×10^{-7}	8×10^{-6}
		Seaweed	2×10^{-7}	8×10^{-6}
Ruthenium 106	16	Fish	1×10^{-5}	1×10^{-3}
		Seaweed	3×10^{-5}	1×10^{-3}
		Sea-bed	5×10^{-4}	1×10^{-1}
		Shore Sand	7×10^{-6}	25×10^{-3}
All Beta-Emitters (excluding Ruthenium 106)	35	Fish	4×10^{-5}	1×10^{-3}
		Seaweed	7×10^{-5}	1×10^{-3}
		Sea-bed	2×10^{-3}	1×10^{-1}
		Shore Sand	3×10^{-5}	25×10^{-3}

Fig. 4. Average discharge and concentration of radio-isotopes.

As regards the ultimate fate of effluent discharged at Windscale, the dissolved and suspended substances would appear to be removed by large-scale tidal eddies from the region between the Cumberland coast and the Isle of Man. Eventually they will pass out of the Irish Sea by the North Channel, partly by eddy diffusion and partly by means of the progressive northward drift. It is estimated that there is a drift through this channel equivalent to about $\frac{1}{3}$ of the volume of the Irish Sea, each year. After leaving the channel the material will have access to the Atlantic, so that the question of accumulation no longer arises.

As regards the fission-product elements which are fixed by adsorption or assimilation close to the point of discharge, the monitoring service appears to show that the activity of the sea-bed, beaches, seaweed and fish has levelled-off, so that discharges could continue at the present rate indefinitely.

The radioactive decay of fission-products also serves to reassure us about the long-term aspects of disposal to sea. If, for instance, 100 curies a day of either caesium-137 or strontium-90 were discharged for an indefinite period, the resulting equilibrium quantity in the sea would not exceed some 10^6 curies. If this were dispersed in a patch of sea 100 miles square and 200 ft. deep, the resulting equilibrium level of radio-activity would be about equal to that of the potassium naturally present in sea-water. The concentration of strontium-90 would be approximately that permissible in drinking water, while that of caesium-137 would be 1/10,000 of the permissible level. The concentration of natural strontium present would be 10^{10} times that of strontium-90, and the concentration of natural caesium 10^6 times that of caesium-137; this dilution by inactive isotopes would of course reduce the concentration factors for the radioactive isotopes in the same proportions. The long half-life of plutonium (24,300 years), on the other hand, and its non-occurrence in the sea, suggest that particular care should be taken in disposing of this element.

Experience at Windscale shows that the disposal of low activity effluent to the sea can be convenient and safe, provided that an investigation of dispersal and concentration processes is made beforehand, and that levels of activity are carefully monitored as long as the process is continued.

Acknowledgment

The author is indebted for much of the information which appears in this article to the authors of the following papers, which were presented at the Geneva Conference on the Peaceful Uses of Atomic Energy:

"The Discharge of Radioactive Waste Products in the Irish Sea."

8/P/418 Part I—"First Experiments for the Study of Movement and Dilution of released dye in the Sea." H. Seligman.

8/P/419 Part II—"The Preliminary Estimate of the Safe Daily Discharge of Radioactive Effluent." H. J. Dunster.

8/P/420 Part III—"The Experimental Discharge of Radioactive Effluents." D. R. R. Fair and A. S. McLean.

L'Evacuation des Produits de Fission de Windscale

La meilleure méthode pour évacuer les déchets de radioactivité faible provenant d'un réacteur, ou d'une installation de processus chimiques situé sur la côte, est celle qui consiste à les déverser dans la mer par tuyaux. Les expériences démontrent que dans le cas très peu probable de calme durant plus de 50 jours, la radioactivité au niveau de l'eau ne dépasserait pas 10^{-4} μc./litre dans le cas d'une évacuation quotidienne de 100 curies par un tuyau long de trois kilomètres. La contamination par algue ou poisson dont la plus importante est celle révélée par la présence de plutonium dans le poisson, peut devenir un facteur restrictif. Les normes maxima de sécurité pour la radioactivité de l'eau de mer, la contamination des poissons et des algues comestibles ont été établies avec une grande prudence. L'expérience faite à Windscale démontre que plusieurs centaines de curies d'émetteurs β et plusieurs centaines de millicuries d'emetteurs α peuvent être déversés avec une entière sécurité. Où le mélange peut se faire dans une étendue de mer raisonnable, les chiffres exprimant la radioactivité stabilisée pour les isotopes de longue vie sont encore bas.

Abfuhr der Spaltprodukte von Windscale

Die bequemste Method, um die Abfälle mit niedriger Aktivität von einem Reaktor oder einem chemischem Werk, die in der Nähe der Küste sich befinden, zu beseitigen, ist die Ableitung durch Röhren in die See. Experimente haben gezeigt, dass unter der Annahme von 50 Tagen andauernder Windstille, was ein höchst unwahrscheinliches Ereignis ist, die Aktivität an der Wasseroberfläche 10^{-4} μc./l nicht übersteigen würde, wenn 100 curies pro Tag durch eine zwei (engl.) Meilen lange Rohrleitung abgeführt würden. Vergiftung durch Tang und Fische könnte der Faktor werden, der die Grenze bestimmt wobei Plutonium in Fischen der wichtigste Faktor ist. Maximale Zahlen für erlaubte Seewasseraktivität, Vergiftung von essbarem Tang und Fischen, sind vorsichtshalber niedrig angesetzt worden. Erfahrung in Windscale hat gezeigt, dass mehrere Hundert curies von β-Strahlern und mehrere Hundert millicuries von α-Strahlern mit absoluter Sicherheit abgeführt werden können. Wo gleichförmige Mischung über ein annehmbares Seegebiet vorkommen kann, sind die Zahlen für eine Aktivität der Isotopen mit langer Lebensdauer noch immer niedrig.

Extracción del Desperdicio de Productos Nucleares de Windscale

El método más conveniente de deshacerse de la materia efluente de un reactor basado en tierra o de una fábrica de productos químicos es mediante el uso de tuberías que descargan los desperdicios en el mar. Los experimentos llevados a cabo han demostrado que en el caso extremamente improbable de 50 dias contínuos de calma, la actividad en la línea de flotación no pasaria de 10^{-4} μc. litros cúbicos en el caso de descargarse 100 curies/d. de una tubería de unos 3 km. de largo. La contaminación de las algas y los pescados pueda que resulte un factor limitativo, siendo el más importante el plutonio en los pescados. Los niveles máximos permisibles para actividad de agua salada, algas comestibles y contaminación de pescados se han puesto bajos, a base de cálculos conservadores. La experiencia en Windscale ha mostrado que varios centenares de curies de emisores β, y varios centenares de milicuries de emisores α, pueden ser descargados con entera seguridad. Donde el mezclado puede ocurrir sobre una zona razonable de mar, las cifras de la actividad de equilibrio de los isótopos de larga vida son siempre pequeñas.

Development of Glandless Pumps

by

J. R. ALLARD, M.A.

Product Sales Manager, Atomic Energy Division, Hayward-Tyler and Co., Ltd.

Glandless pumps whilst eliminating leakage of the circulating fluid introduce special problems of insulation and bearing design. Two types of pump currently manufactured by Hayward-Tyler and Westinghouse respectively are taken as examples of the methods used to overcome these difficulties.

MOST glandless pumps for nuclear energy applications have been developed from the squirrel-cage submersible types used in boreholes, although pumps with magnetic couplings have been used to a small extent. A cross-section of a typical glandless pump is shown in Fig. 1, and it should be noted that the motor bearings are lubricated by the fluid being pumped. The heat generated in the motor and that coming from the hot liquid in the pump is carried away by a small quantity of liquid circulating in a closed system between the motor and an external cooler. The circulation is caused by an impeller incorporated in the thrust disc, and a jacket is fitted round the neck to remove the heat flowing from the pump to the motor when the latter is not running. The construction of these pumps limits them, in general, to single-stage duties with single entry impellers, and their main use is consequently as circulation pumps.

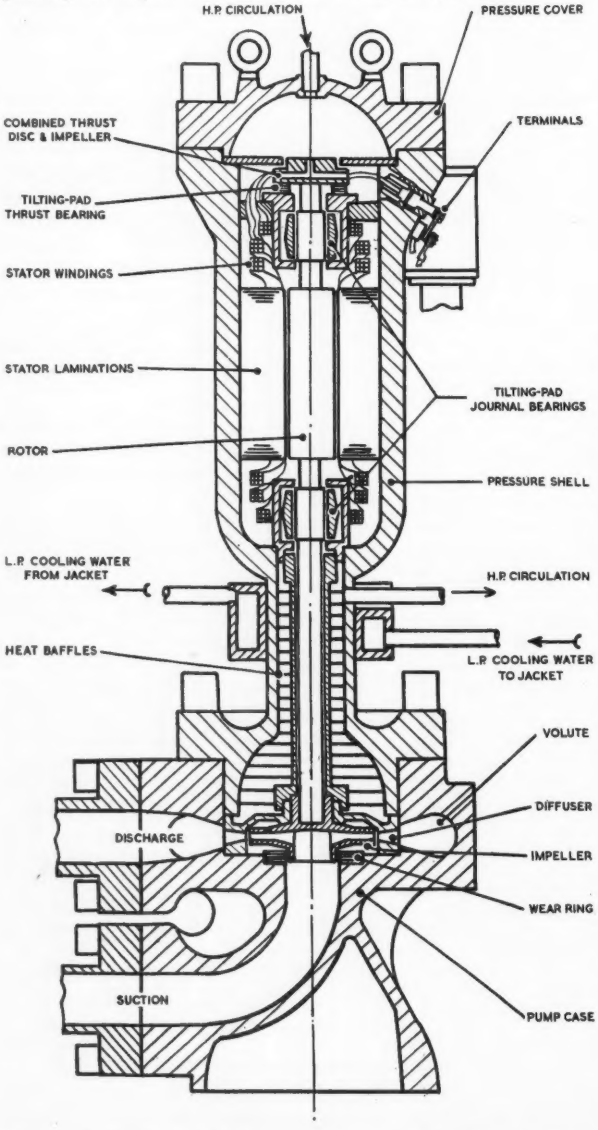


Fig. 1. Cross-section of a Hayward-Tyler glandless pump in which, it will be seen, the motor bearings are lubricated by the fluid being pumped.

Typical Applications

(a) Cooling of heat exchangers or other apparatus with light water not normally exposed to radiation.

(b) Circulation of high-pressure water in power-producing reactors, test loops, etc.

(c) Circulation of low-pressure light or heavy water in research reactors.

(d) Circulation of uranium in acid solution; e.g. in homogeneous reactors or fuel processing.

(e) Circulation of thorium or uranium slurries; e.g. in homogeneous reactors or fuel processing.

(f) Circulation of liquid metals, sometimes with dissolved uranium; e.g. in reactors or heat-exchange systems.

(*a*) *Cooling with light water not exposed to radiation.* Glandless units are generally used for such duties because they are more reliable than pumps fitted with glands or seals. In a coal-fired boiler with forced circulation the result of a pump failure is generally limited to the burning-out of a few tubes, but in a reactor the damage caused by overheating can be much more severe; for example, contamination due to failure of a fuel element. Reliability, therefore, is of major importance. To achieve a running life of several years without maintenance the main problems which had to be solved were those of finding suitable insulation for the windings and the development of water-lubricated bearings capable of taking high loads.

Over a period of years PVC has generally come to be regarded as the most suitable insulation for water-filled motors. It softens only gradually over a wide range of temperature, enabling it to withstand overheating for short periods without failure, and it is cheap and relatively easy to extrude on to wire and to mould for star joints and terminal seals.

The variation in the deformation under load of PVC with temperature can be determined experimentally, and this information is used by the motor designer when choosing a suitable thickness of insulation and a maximum normal operating temperature for the motor.

A test laid down by the Admiralty[1] is useful for comparing the deformation of different grades of PVC or other plastics. The thickness of insulation necessary is determined by the supply voltage, damage likely to be sustained in winding, and deformation at maximum working temperature. The last factor is largely empirical and the temperature chosen is at the manufacturer's discretion.

Other plastics, such as PTFE, with higher melting points could be used, but it is doubtful if they would be economic as any significant increase in water temperature would affect the bearing design owing to the lower viscosity of the water:

1. G.D.E.S. No. 18/1949.

for example, the Hayward-Tyler motor with PVC insulation is designed for about 140° F. water temperature, whilst the Westinghouse with Class H insulation is designed for 200° F. (Fig. 2).

In an ordinary submersible motor the forces on the journal bearings due to dynamic and magnetic unbalance of the rotor can generally be taken with plain journal bearings. In a glandless pump, where the impeller is carried on the rotor-shaft extension, the radial load on the impeller—due to uneven pressure distribution round the volute—must also be taken by the motor bearings, so that the load they have to bear is increased.

If the bearings can be designed to operate with full fluid film lubrication then wear will be minimized, but to achieve this with a plain water-lubricated journal bearing is not easy, as it involves running with very fine clearances between the bush and the shaft sleeve.[2]

The load on the bearings can be reduced by shortening the overhang of the impeller, and using self-aligning plain journal bearings made of materials which do not gall when starting, have low rates of wear and are able to run under conditions of partial film lubrication if necessary. This appears to have been the solution adopted by Westinghouse in the United States who have carried out an extensive development programme on water-lubricated bearings. They found that very hard materials such as tungsten carbide, stellite and ceramics were satisfactory, particularly when used with certain carbon graphite materials.

Another method of approach is to achieve full fluid film lubrication by using a ring of tilting pads, such as are more normally used in Michell thrust bearings. In the Hayward-Tyler pump a sleeve of mineral-filled phenolic material runs against a ring of stainless steel pads which also serves to provide axial self-alignment. This type of bearing has been used for a number of years in this country so that little development work was needed, the main problems being those of manufacture.

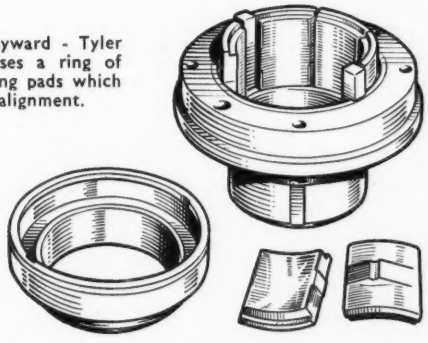


Fig. 3. The Hayward - Tyler journal bearing uses a ring of stainless steel tilting pads which provide axial alignment.

The loadings which Westinghouse found to be suitable for their bearings are much lower than those currently in use in this country for bearings incorporating plastics, and this appears to be reflected in their design. For example the Hayward-Tyler pump is normally of single wear-ring impeller construction, whereas the Westinghouse design reduces the axial load on the thrust bearing by using a double wear-ring This has a lower efficiency and is more difficult to machine. The load on the journal bearings in the Westinghouse pump is further reduced by having a shorter overhang for the impeller, thus reducing the over-all height at the expense of increased cooling-water supply. It should be pointed out, however, that plastics bearings would be unsuitable if exposed to intense radioactivity.

The use of "hydrostatic" bearings with pockets in the bush fed with water under pressure has also been proposed, but

2. Dr. P. Fortescue. Jnl. Nuclear Energy, 1956, Vol. 1.

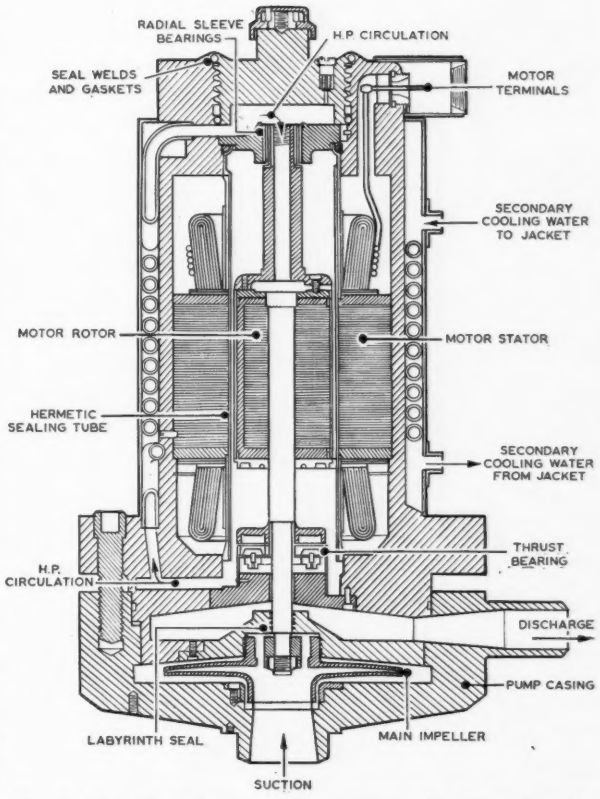


Fig. 2. The Westinghouse glandless pump with Class H. motor insulation is designed for water temperatures up to 200° F.

little information is available about the performance of such bearings, particularly in large motors.

(*b*) *Power reactors with water as heat-exchange medium.* Where water as the heat-exchange medium is circulated through a power-producing reactor, certain additional features are demanded of the pump. First, the motor must be made of materials which can resist the small amount of radiation in the water passing through the pump; this rules out PVC as an insulator. Polythene is used, therefore, because of its greater resistance to radiation, and better electrical characteristics. It has a sharp melting point at about 100° C. so that it does not provide the same margin of safety as PVC, but, in a reactor system, the higher standard of operating personnel should reduce the chances of ill-treatment of the unit. Considerable development work on the moulding of pressure-tight cable and terminal joints was necessary.

Secondly, the unit must not contain materials which can go into solution and get into the reactor circuit. To some extent this affects the choice of bearing materials and insulation, and also means that if copper rotor bars are used they must be isolated from the water by a sheath round the rotor. In small motors solid rotors of stainless iron have been employed but the electrical losses involved rule out this form of construction for motors of more than a few horse-power. In larger motors with laminated rotors aluminium is used instead of copper for the short-circuit rings and rotor bars to overcome this problem.

Thirdly, the pump must be able to withstand the corrosion-erosion of hot high-pressure water containing radiolytic oxygen so that corrosion products in the circuit will be minimized. To meet this, the pump volute and impeller are generally made of stainless steel. If the impellers are small it may be necessary to fabricate them instead of using castings, owing to machining difficulties.

Fourthly, the motor, which will operate at comparatively

low temperatures, must withstand the action of water containing oxygen—possibly with a low pH value—so that there will be a minimum of corrosion products circulating through the motor bearings. In any case, to reduce the amount of cooling water required the pump and motor are designed to minimize the interchange of water between pump and motor. This requirement rules out ordinary electrical sheet steel for the motor laminations, and a 14% chromium iron is normally used instead. The motor case is made of stainless steel or of mild steel lined with stainless steel.

(*c*) *Cooling of research reactors.* In low temperature research reactors much of the circuit may be in aluminium, and in such applications aluminium conductors in the stator are essential to minimize the damage which might be caused by a failure of the insulation. Where heavy water is the coolant it is necessary to design the unit so that it has a minimum hold-up of water, and can be completely drained.

(*d*) *Acid solutions of uranium.* If the uranium solution is radioactive, decontamination of the motor may present a problem and for such duties a "canned" stator construction in which the laminations and windings are isolated by a thin sheath may be preferable, in spite of its lower efficiency. However the choice of a suitable material for the sheath to withstand the corrosion-erosion action of a highly acid solution is not easy and may involve the use of noble metals.

Whilst canned stators have been widely used in the United States, the development of this form of construction from the canned stator borehole motors common in Britain presents a number of problems. These motors normally have oil-filled stators, and O-rings or some other form of gasket to seal the stator sheath, as the pressures encountered in such applications are not high. A typical nuclear application of such a motor, however, might involve pressures of 2,000 p.s.i. and horse-powers in excess of 1,000; also, oil is not suitable for stator cooling because of the possibility of contamination if the stator sheath were punctured. The main development problems consequently centre on the sealing of the ends of the sheath, the cooling of the motor windings, and the troubles due to eddy-current heating of the sheath.

(*e*) *Slurries of uranium and thorium.* Where slurries are being handled it is advisable that those pump components in high-velocity areas should be made of titanium to reduce the effects of erosion, although much depends on the sharpness of the slurry concerned.

The use of hard materials for the bearings in the motor will reduce the rate of wear, but the high specific gravity of the metals in the slurries will cause them to be flung to the periphery of the water rotating in the motor and this will also cause trouble. The water circulating through the motor must, therefore, be kept as free from particles as possible. This can be done by incorporating a filter in the circulating system of the motor or by maintaining a sufficient flow of water from the motor to the pump to prevent any particles reaching the motor. To do this it is necessary to bleed a small amount of clean water into the motor so as to maintain a constant flow outwards through the neck between the motor and the pump. The amount of water which can be bled into the system is limited by the amount which can be bled out through the purification system; as a result, the pump and motor have to be designed with this limitation in view.

(*f*) *Liquid metals.* For handling liquid metals, particularly bismuth, it seems probable that glandless pumps should have much higher efficiencies than electromagnetic ones, so that there is naturally considerable interest in such applications. A canned stator is essential but, owing to the comparatively low pressures involved, some of the problems associated with taking higher pressures across the sheath—as in a pressurized water system—are simplified. When handling bismuth the temperatures involved are much higher than with sodium and the insulation of the stator windings presents a problem.

Conclusions

Glandless pumps are used in nuclear engineering work because of their reliability and/or leak tightness. Most of the problems connected with them have been solved, and the solution of the remaining ones is mainly dependent on the gaining of experience under running conditions and the availability of materials in suitable form.

It will be appreciated that there is a considerable amount of design work in the motors of these units and consequently the range of available sizes is not as large as those of dry motors, although it is continually increasing. In general, impeller specific speeds of less than 3,000 are preferred for the large sizes, and less than 2,500 for the smaller sizes. Very low specific speeds should be avoided as the impellers have to be designed so that all the internal passages can be cleaned.

Développements des Pompes sans Presse-Etoupe

La nécessité d'éliminer tout suintement des circuits liquides dans une installation de réacteur a amené des développements nouveaux dans la construction des pompes sans presse-étoupe. On compare deux types, l'un de fabrication Hayward-Tyler en Angleterre, et l'autre de fabrication Westinghouse aux Etats-Unis. On utilise généralement le PVC pour assurer l'étanchéité des pompes transportant des liquides actifs, mais il faut employer du polythène pour des dispositifs pompant des liquides radioactifs. L'usure occasionée par le chargement inégal des paliers peut être réduite en maintenant court le porte-à-faux de l'arbre de l'impulseur, en utilisant de simples douilles d'un matériau très dur, ou en réalisant une lubrification par couche mince continue grâce a l'emploi d'un anneau de coussinets pivotants. Des matériaux spéciaux peuvent être nécéssités pour la volute de la pompe, pour l'impulseur et pour les laminations du moteur. L'emploi des solutions acides d'uranium et des suspensions de l'uranium et du thorium présentent des problèmes spéciaux de construction, particulièrement en ce qui concerne la protection du moteur.

Entwicklung Stopfbuchsenfreier Pumpen

Die Notwendigkeit zur Vermeidung von Lecks in Flüssigkeitsstromkreisen in Reaktorwerken hat zu weiterer Entwicklung in der Konstruktion von stopfbuchsenfreien Pumpen geführt. Zwei Typen werden verglichen, die eine hergestellt von Hayward-Tyler in England, die andere von Westinghouse in den Vereinigten Staaten. PVC wind allgemein benutzt, wo es sich um den Schutz von Pumpen handelt, mit denen nicht aktive Flüssigkeiten gefördert werden, Polythen muss verwendet werden, wo radioaktive Lösungen gepumpt werden sollen. Abnutzung durch ungleiche Belastung der Lager kann reduziert werden, indem man den Ueberhang der Läuferwelle gering hält, durch glatte Lager aus sehr hartem Werkstoff, oder durch ausgesprochene Flüssigkeitsfilmschmierung mittels eines Ringes von kippbaren Schmierschuhen. Spezielle Materialien könnten für den Pumpenkörper, den Läufer und die Motorlamellen erforderlich werden. Saure Lösungen von Uranium und Schlamm von Uranium und Thorium ergeben spezielle Probleme für die Konstruktion, insbesondere im Hinblick auf den Motorschutz.

Evoluciones en Bombas sin Casquillo Prensaestopas

La necesidad de eliminar las fugas de los circuitos líquidos en las instalaciones de reactores ha resultado en nuevas evoluciones en el diseño de bombas sin casquillos prensaestopas. Dos tipos, uno fabricado por Hayward-Tyler de Inglaterra y otro por Westinghouse de los E.E.U.U. son comparados. El "PVC" está en uso general como un aislamiento en las bombas que manejan fluídos inactivos, pero hay necesariamente que emplear el politeno en las unidades que bombean soluciones radioactivas. Se puede reducir el desgaste de los cojinetes causado por el cargado desigual, manteniendo corta la proyección lateral sobre el eje propulsor, con gorrones simples de material muy duro, o en alcanzar una lubrificación plena de película de fluído mediante el uso de un anillo de almohadillas inclinables. Es posible que se necesiten materiales especiales para la voluta de la bomba y las laminaciones del propulsor y el motor. Las soluciones ácidas de uranio y las lechadas de uranio y de torio presentan problemas especiales en cuanto a diseño, particularmente con respecto a la protección del motor.

Radio-isotope Production in Britain

by
E. N. SHAW, B.Sc.

Business in radio-isotopes is increasing steadily as shown by the figures for 1955. New reactors will provide higher specific activities. The design and manufacture of "safe" industrial sources is an important feature of production.

ARTIFICIALLY produced radioactive isotopes were first delivered to an organization outside the Ministry of Supply's Atomic Energy Division in September, 1947, but it was not until late 1948 that radio-isotopes became available in any quantity. Since that time the demand and supply has steadily risen. Fig. 1 shows the curve of the number of shipments over the period 1948-1955.

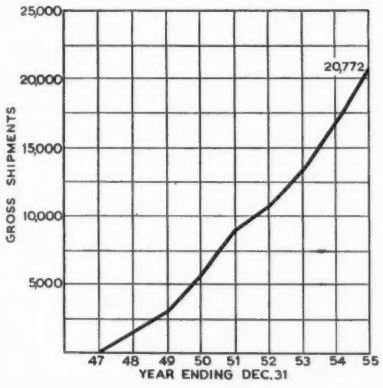


Fig. 1. Combined figures for the total number of shipments from Harwell and Amersham, 1947—1955.

Requirements of radioactive materials can be divided into five main categories:

(1) Amersham for processing—regular shipments include irradiated tellurium for extraction of I 131, sulphur for P 32, nitrogen for C 14, gold, thallium and mixed fission products.
(2) hospitals—for example sodium, chlorine.
(3) radiac sources—in general cobalt.
(4) industry — large quantities of radiographic sources particularly.
(5) overseas — covering the whole range.

Amersham is of course one of the principal customers, for resale, taking 20% of the output. The overseas market, however, is considerable covering more than 50 countries and represents nearly 30% of the total. America is the second most important customer, importing $23,000 worth over the past 12 months. Radiac sources, whilst primarily designed for Civil Defence use, are in general demand as standard sources for research, education and so on.

The continued upward trend of the shipment curve implies that saturation is still a long way off. It is expected that medical demands will continue to rise for some time both for processed and unprocessed materials and that the present requirements of industry represent only a small fraction of the future possibilities. It is probable that, although overseas demands will continue to rise for the next two years, the reactors being built on the Continent and in Asia will limit sales. With a relaxation of the regulations governing export from the U.S.A. greater competition must be expected from that quarter.

At the Radiochemical Centre, Amersham, where routine extractions are carried out, labeled compounds prepared, some fission products separated and industrial-type sources manufactured, increasing demands, coupled with the increasing variety available, are establishing a rapidly expanding business. The value of this trade during 1955 was approximately £500,000, including £200,000 in overseas sales.

Production in BEPO has been supplemented since 1951 by irradiations in the Windscale piles, notably long-lived high-activity radio-isotopes such as cobalt-60. The maximum slow neutron flux available for isotope production in BEPO is 12×10^{11}n/cm.^{2}/sec. (pile factor 12) and although the flux at Windscale is still secret it is known to be at least equal to that in BEPO.

The heavy water reactor E443 is due for commissioning in June and two months later will be used for irradiation purposes. The flux available is expected to be a maximum of 10^{14}n/cm.^{2}/sec., thus providing a very considerable increase in specific activities obtainable. It will be possible to rent DIDO'S facilities for irradiations at a figure of £10 to £100 a day, depending on the total flux, space and time required.

As a general rule BEPO is shut down on Monday morning and unloading begins at 6 a.m. This is usually completed by 10 a.m. and loading is carried out during the rest of the day in preparation for the pile to be started up at 6 p.m.; it is possible that the continuous running time will be increased to two weeks in the near future. Outside these times, and for short irradiation periods,

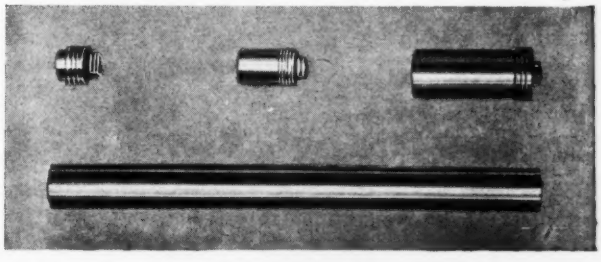
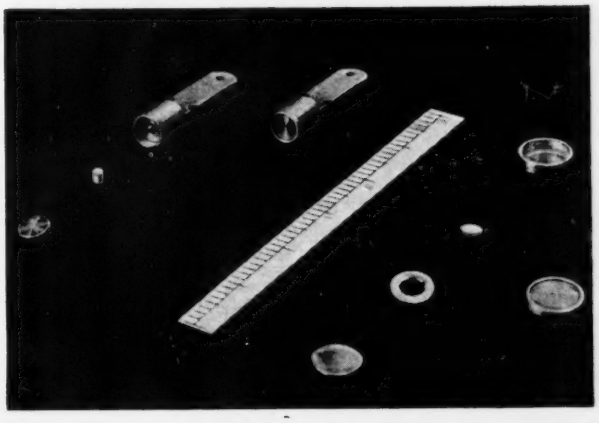
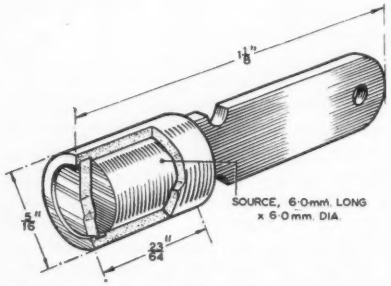


Fig. 2. (Left) Upper row shows Al cans for insertion into BEPO. Lower cylinder is typical of Windscale cans.



(Right) Two types of high activity compacted sources. Radiographic source is on the left and to the right of the ruler is a flat source, e.g. Tm 170.

a "self-serve" system can be operated whereby a small number of samples can be passed through with the pile operating. In general samples are contained in sealed polythene packets which are placed in aluminium cans fitted with screwed lids (Fig. 2). These cans are mounted in a carbon "stringer" which consists of a series of drilled carbon blocks hinged together to form a continuous loop through the biological shield and into the reactor. An illustration of this can be found in "The World's Reactors: No. 1" elsewhere in this issue. Special containers can be fed into BEPO through vertical experimental holes and low flux cavities are available for bulk irradiations.



Sectional drawing of radiographic source holder used for Co 60, Ir 192, and Cs 137 particularly.

The Windscale production piles are shut down much less frequently and the normal cycle of operations is generally two months. Raw materials are canned in hermetically-sealed aluminium containers, and are best extracted chemically. The dates of unloading at Windscale are liable to a fair degree of uncertainty and in general irradiations in this reactor are confined to radio-isotopes for stock-piling.

When E443 becomes available it is expected that the cycle of operations will be fortnightly, but again facilities will be available for shorter term irradiations in the experimental holes. Canning techniques will probably be similar to those in BEPO.

Industrial Sources

Considerable effort has been spent at the Radiochemical Centre on the development of radioactive sources for installation in non-laboratory conditions which will minimize the spread of radioactivity in the event of an accident. In the main these fall into two groups: rolled foils and sealed capsules. The first have particular application for such instruments as beta gauges and the second for radiographic sources. The different treatment in the two cases lies in the difference between emissive requirements for alpha and beta ray sources and gamma ray sources.

Foils of various strengths are produced in strontium, ruthenium, cerium, promethium, thallium and radium. The β-ray sources, except thallium, are formed from a billet composed of silver—powdered radioactive salt—silver, cold-rolled into a finished foil, to leave a thin covering face but a substantial backing. The actual weight of radioactive salt is negligible and fine dispersion into the crystal lattice of the silver takes place during rolling. Separation of the salt from the silver is possible only by chemical means and the finished foil will thus withstand considerable ill-treatment without risk of contaminating its surroundings. As an additional precaution sources are made up individually to allow a continuous perimeter of inactive silver (fig. 3).

For radium the radioactive material is initially made up in the form of a dispersion of radium in gold. A maximum covering layer of 0.0001 in. only is permissible to allow adequate α particle emission.

Until recently thallium sources were prepared by plating the metal from the active chloride solution on copper foil and covering with a thin plating of zinc. The finished product was not as stable as the rolled foil and if wrapped in a confining envelope would deteriorate with time, probably as a result of the action of highly ionized moist air continuously in contact with the surface. Under conditions where a reasonable air flow was permitted around the surface, however, corrosion took place only slowly. With the greater specific activity of thallium now available the Radiochemical Centre has developed a system of deposition similar to that of the strontium. The silver is replaced by a light alloy and the rolling technique has been modified. The finished source is robust and proof against corrosion.

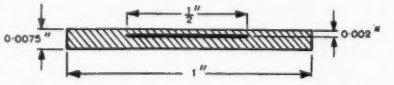
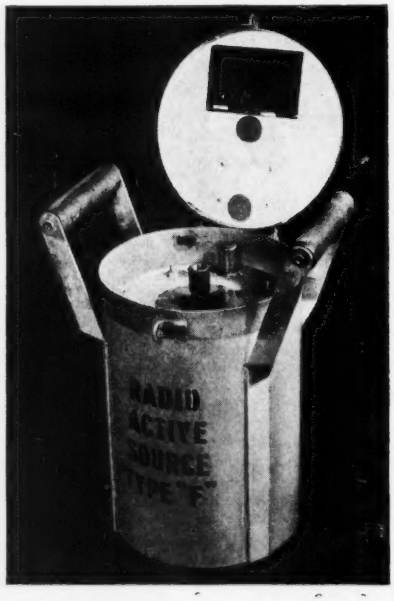


Fig. 3. Cross-section of a Sr 90 rolled foil.



Typical Radiac source container as used for civil defence instructional purposes or general transport work. The graph is for plotting decay curve.

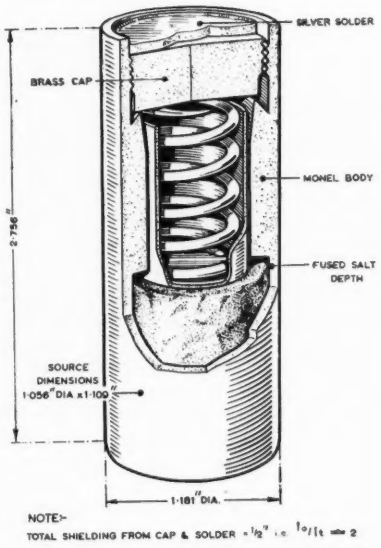


Fig. 4. Proposed container for multicurie caesium sources. Salt is fused directly into the cylinder.

Multicurie Sources

Supplies of separated fission products are limited at present to relatively low activity sources, the maximum caesium source obtainable being six curies. These are made up for industry by compacting a pellet of active caesium sulphate and sealing into a gold container. This in turn is mounted in a light alloy holder similar to the standard radiographic sources of cobalt and iridium. In the near future the pilot extraction plant at Windscale will be operating and is expected to produce 2,000 curies per month maximum. The complete caesium output of this plant has already been booked for therapeutic purposes for two years. It is hoped that a plant capable of producing megacuries/yr. will be in operation in four years time.

Multicurie caesium sources will be prepared in the type of container shown in Fig. 4. Caesium sulphate is fused into the monel metal cylinder at a temperature of 1,000°C. and the solidified pellet is retained in position by a spring and brass cap.

Tentative preparations have been made for the deposition of point multicurie sources of strontium for use as Bremstrahlung sources and for possible developments in storage batteries.

La Production des Radio-isotopes

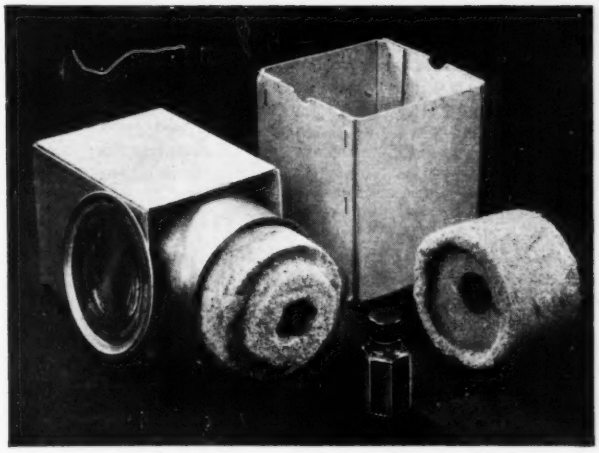
Les expéditions de matériaux radioactifs en provenance de Harwell et Amersham pour l'année se terminant le 31 décembre 1955 sont brièvement examinées. Les chiffres d'exportation pour l'année ont une valeur totale de presque 250.000 livres sterling. La concurrence des Etats-Unis, aussi bien que la construction des réacteurs sur le continent et en Asie, tendront à modifier le cours régulièrement montant. Les réacteurs britanniques capables de production sont discutés au point de vue du flux de neutrons et de cycle d'opération. L'emploi de DIDO multipliera plus de dix fois l'activité spécifique. On traite des méthodes de production pour sources de type industriel, notamment en feuilles et les sources radiographiques, y compris une nouvelle méthode de préparation de sources caesium de haute activité. On insiste sur l'importance de la robustesse d'une source radio-active qui doit être maniée en dehors du laboratoire.

Produktion von Radio-Isotopen

Der Versand von radioaktiven Stoffen von Harwell and Amersham in dem Jahr, des am 31. Dezember 1955 geendet hat, wird kurz analysiert. Exportzahlen für das Jahr zeigen einen Gesamtwert von beinahe 250.000 Pfund. Der Wettbewerb der Vereinigten Staaten wird die stetige Neigung zum weiteren Anwachsen modifizieren, ebenso wie das auch die Folge des Baues von Reaktoren auf dem Kontinent und in Asien sein wird. Britische Reaktoren, die Produktion aufnehmen können, werden diskutiert mit Bezug auf Neutronenfluss und den Kreislauf der Operationen. Der Einsatz von DIDO wird eine Zunahme der spezifischen Aktivität um das Zehnfache gestatten. Produktionsmethoden für industrielle Ausgangsstaffe, insbesondere Folien und radiographische Staffe werden behandelt unter Einschluss einer neuen Methode zur Herstellung von hochaktiven Caesimmassen. Besonderer Wert wird auf die Robustheit der radioaktiven Stoffe gelegt, um sie ausserhalb des Laboratoriums handhaben zu können.

Producción de Radio-isótopos

Se hace un análisis breve de los embarques de materiales radioactivos de Harwell y Amersham por el año que finaliza el 31 de diciembre de 1955. Las cifras de exportación para el año señalan un valor total de cerca de £M¼. La competencia de los E.E.U.U. tenderá a modificar la progresiva tendencia alcista, como así también lo harán la construcción de reactores en el Continente Europeo y en Asia. Los reactores británicos capaces de producir se discuten en términos de "flujo neutrónico" y ciclo de operación. El empleo de DIDO permitirá un aumento de actividad específica por un factor de más de diez. El método de producción de fuentes del tipo industrial, particularmente las fuentes de hojas metálicas y radiográficas son discutidos, incluyendo un nuevo método de preparar las fuentes de cesio de elevada actividad. Se hace mucho hincapié con respecto a la robustez de una fuente radioactiva que va a ser manejada fuera del laboratorio.



Liquid sources are packed in sealed ampoules which in turn are sealed into cans containing absorbent fibre. Cans are sent in cardboard boxes.

The Transport of Radio-isotopes

ATTEMPTS have been made to build up rules and regulations for the transport of radioactive materials which will be applicable in countries all over the world. Although a considerable amount of discussion has taken place it is only with air transport that any measure of finalization has been achieved. Rulings in individual countries tend not to differ to any extent, only in small details, and frequently certain differentials must be maintained because of peculiar local conditions.

Air transport.—The International Air Transport Association has made recommendations that have been adopted in most countries. The regulations cover the transport of alpha, beta, gamma and neutron radiating materials. Total quantities that can be carried in any one aircraft have been defined in terms of disintegration rate and ionizing power of radioactive sources. So far as individual packages are concerned the general ruling limits the radiation on the outside of the container to 200 mr/hr. or the equivalent. Additional regulations also make provision for the dose rate at one metre to be checked, and packages are classified into groups on this basis.

Containers in general fall into three classes: those which are specifically beta packages and liquid-containing packages and which rely on an absorbing medium such as wood shavings to absorb any spillage; those which depend on a small thickness of lead; and those which take advantage of the R^2 law. In addition high activity gamma sources can be placed in the wings of some aircraft without additional shielding. Special arrangements must be made to have the aircraft met at its destination.

Rail transport.—Differences in the size of railway carriages and trucks on American railways and British have prevented identical rulings being adopted. The regular use on United States railways of large carriages enables a greater degree of segregation to be adopted and hence packets with greater surface dose rates can be accommodated. In the United Kingdom it has been provisionally agreed that there shall be two classes of package the first of which will be accepted as a normal passenger train parcel, providing radiation at the surface is not greater than 10 mr/hr. The "class two" package can have up to thirty times this level of radiation at the surface provided that due warning is given to the railway authorities and provision made for the train to be met at the destination by a representative of the customer.

Road transport.—Many of the deliveries from Harwell are made directly by road particularly in the London area and when short-lived isotopes are involved. Special cars are employed which are a cross between a large limousine and a van, so that a reasonable number of boxes can be taken at one time while still keeping the driver at a reasonable distance. Present regulations insist that the dose at the driver's seat (or passenger seat) shall not exceed the *maximum permissible level* and at no point on the outside of the car should it exceed 16 times this figure.

Sea transport.—Regulations covering the shipping of radioactive materials are at present in a state of flux, partly because of the probable necessity of accommodating irradiated fuel elements. Whereas on the sea a comprehensive ruling must be adopted, it is probable that land vehicles, and possibly aircraft, will be specially equipped for such freight. For the moment packets are accepted which have a dosage of 200 mr/hr. at the surface providing that the dose at one metre does not exceed the *maximum permissible level.*

Postal transport.—Limited quantities of radioactive materials can be sent through the post providing prior approval has been obtained from the G.P.O. Engineering Section of the type of package to be employed. Radiation on the surface of this package must not exceed 20 mr per 24 hours. There are no facilities for postal transport of packets that have higher dose rates because of the insuperable problems of segregation.

Dounreay Fast Reactor Model

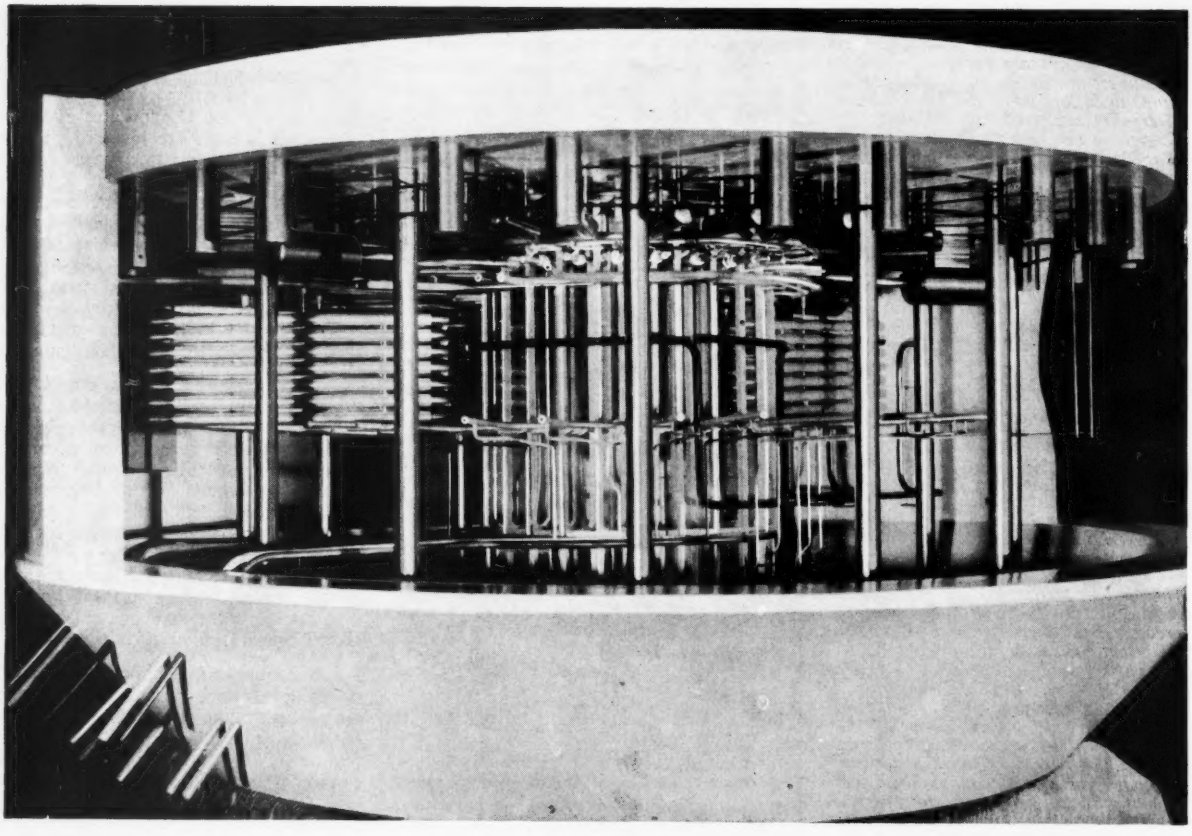
The construction of accurate scale models assists not only in demonstrating a particular assembly but also in checking theoretical calculations. This model of the fast reactor at Dounreay shows the disposition of the primary heat exchangers and pumping circuits relative to the core. A brief description of the operation of the reactor is appended with some comments on the safety precautions.

A scale model of the fast fission reactor at Dounreay has been built by John Thompson Ltd. of Wolverhampton to assist in the finalization of design drawings and to allow detailed plans for construction to be worked out. All the pipework and scaffolding must be stored within the concrete shields and the reactor assembly built up before erection of the coolant circuits can begin. Communication with the outside world can then only be made through four small ports.

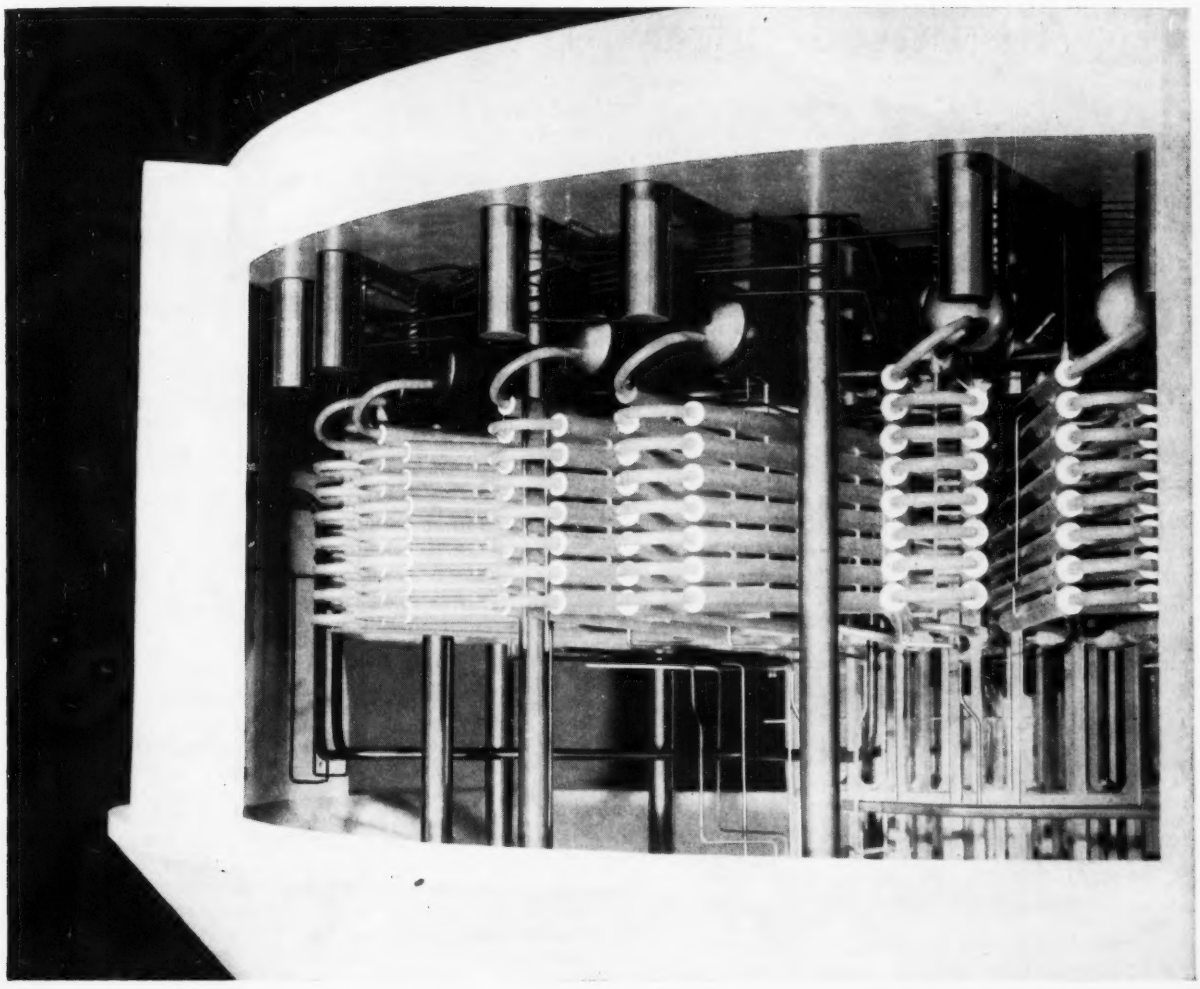
Fuel elements of uranium-235 in a right cylinder 2 ft. x 2 ft. surrounded by a tamper of natural uranium, depleted uranium or thorium, are mounted inside the main sodium coolant pot. Reactivity control is exercised by adjustment of the relative positions of the elements, access to which is obtained through a system of eccentric shields sealed with a nitrogen pressurized liquid. Demountability is one of the features of design to facilitate experimentation on the fuel and breeding materials and to permit rapid removal of the core in the event of a disaster. Surrounding the sodium pot is a neutron shield of carbon, the outer layer of which contains boron. Accurate determination of operational power can be made down to very low levels by slow neutron flux measurements in chambers let into the inside of the carbon shield. The minimum level of power is maintained by a neutron priming source.

The coolant circuits have been designed to dissipate over 60 megawatts of heat even with part of the pump circuits inoperative. Safety considerations have decreed a very conservative rating of all units. The primary coolant circuit is of sodium exchanging to a secondary circuit again of sodium or sodium potassium alloy which, in turn, exchanges to the water system. Excess heat from this system is dissipated in a sea-water condenser.

The primary circuit consists of 24 parallel loops each comprising two separate heat exchangers. Twenty of these pairs feed directly into the top of the sodium pot while four provide cooling for the blanket. Each loop is independently equipped with an electromagnetic pump and a cold trap purifier through which a small percentage of the primary circuit is bled. The nearly radial assembly of the heat exchangers can be seen clearly in the photographs but for clarity the lagging has been removed around the U-sections



Cut-away view of the Dounreay fast reactor with the nearside heat exchangers removed showing the coolant loops emerging from the reactor core and passing out through the concrete shielding.



A close-up view of the reactor. Note that part of the lagging on the heat exchangers has been removed. Horizontal cylinders at the top are the E.M. pumps near which are disposed the cold traps in vertical cylinders. The concrete shield at the bottom takes up the shape of the containing sphere which is 135 ft. in diameter. The upper half of the sphere (not shown) contains lifting equipment for the core materials.

—normally, of course, the lagging would be continuous. The primary heat exchangers are made up of concentric stainless steel tubes through the centre of which flows the primary (and radioactive) sodium. Sections of the primary circuit not enclosed by the secondary circuit and external to the reactor are enclosed in a pressurized nitrogen jacket equipped with leak detection apparatus.

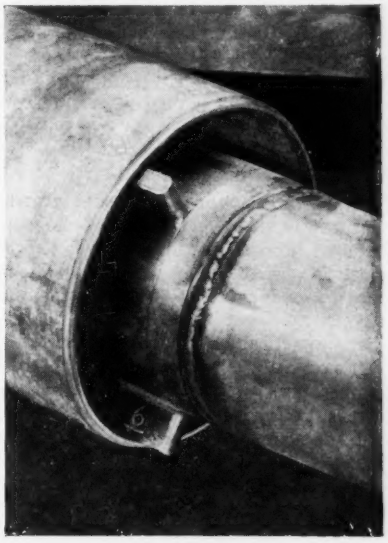
In the event of power failure in one of the sections or faults developing in, say, the tubes or electro-magnetic pump, the individual section can be shut off by nitrogen pressure and the reactor will operate safely on the remaining heat exchangers.

Valves have been eliminated entirely from the design. Due to the decay of fission products, considerable heat release continues after the reactor has shut down. This shut-down may have been caused by a major power failure in the primary coolant circuit and provision has been made for a thermo-siphon system to operate with sufficient heat capacity to maintain the core temperature at a safe level.

The secondary liquid-metal coolant circuit passes through the biological shield to a sodium-water heat exchanger constructed with a double wall and pressurized with nitrogen to make intermixing of water and sodium as a result of tube failure impossible. The nitrogen circuit is equipped with leak detection and any failure in one circuit will be immediately discovered and the exchanger taken out of commission and drained.

Apart from the cooling of the reactor itself and tamper, provision has been made for air cooling of the neutron and concrete shields.

Stainless steel has been used throughout (that is, where constructional metals were applicable) but this may represent an unnecessary extravagance. As stated above, however, safety precautions have been of paramount importance in the design and location of the reactor. Experience will no doubt indicate where economies can be made in the future.



Stage in the welding of the stainless steel heat exchangers. All welds are radiographed and the tube leak-tested with N_2O before acceptance.

An Introduction to Nuclear Energy

In this article the author attempts to give a general outline of the basic principles of nuclear energy leading up to a brief description of the more important types of nuclear reactor. Many readers of this journal will already be familiar with the ideas of nuclear physics and the article is not intended for them. It is aimed rather at those engineers and industrialists who are not yet directly involved in any particular atomic-energy project or technique, but who may reasonably expect a new journal to put them in the picture with the help of an introductory review written in simple language.

by

J. M. KAY, M.A., Ph.D.,
A.M.I.Mech.E.

FOLLOWING the pioneer work of Bohr and Rutherford, the atom can be pictured as comprising a small but relatively massive *nucleus* surrounded by a planetary system of electrons. The nucleus of an atom is believed to be made up from two fundamental particles—the *proton* and the *neutron*. These two particles have nearly the same mass, but the proton carries a positive electrical charge whereas the neutron is electrically neutral. The *electron*, which is normally found outside the nucleus, carries a negative charge and has a mass which is much smaller than that of the proton or neutron.

In Fig. 1 three different atoms are shown diagrammatically —hydrogen, deuterium, and helium. The hydrogen atom, which is the simplest of all and the first element in the chemical table, has a nucleus consisting of a single proton.

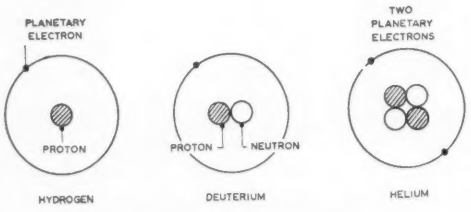


Fig. 1. Hydrogen, deuterium and helium atoms.

The deuterium or heavy hydrogen atom has a nucleus consisting of a proton and a neutron. Helium has a nucleus comprising two protons and two neutrons.

Deuterium or heavy hydrogen is chemically similar to ordinary hydrogen because the chemical identity of an atom is fixed by the number of protons in the nucleus, but it has slightly different physical properties. This is the simplest example of an *isotope*. If an atom has the same number of protons as another atom, but a different number of neutrons, it is said to be an isotope of the other atom.

Chemical and nuclear reactions

Chemical reactions involve the rearrangement of atoms to form different molecules. This chemical linkage of atoms is brought about by the transfer or sharing of planetary electrons, the nuclei of the atoms remaining unaffected by the process. As an example, the combustion of hydrogen and oxygen to form a molecule of steam or water is shown diagrammatically in Fig. 2. Hydrogen and oxygen, however, will not react spontaneously when mixed together at room temperature. The mixture must be heated until it attains a certain energy level at which the reaction can start, and it may then proceed in a more or less explosive manner. The internal energy of the H_2O molecule is less than that of the constituent atoms at the same temperature. Energy is consequently released in the form of heat and the reaction is said to be exothermic.

It can be seen from Fig. 2 that the nuclei of the atoms are unaffected, only the planetary electrons playing an active part in the process.

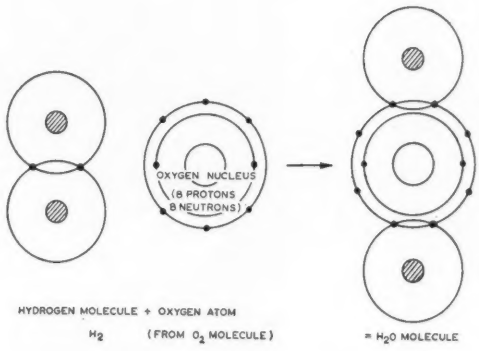


Fig. 2. A chemical reaction.

By contrast, a possible *nuclear reaction* is illustrated diagrammatically in Fig. 3. This shows the combination or fusion of two deuterium atoms to form one helium atom. Here it is the nuclei which are involved in the reaction, and the electrons play no part in the process. As in the case of the chemical reaction the constituent atoms must have their energy level raised before the nuclear fusion reaction can occur. The energy level or temperature required in this case however is very much greater than that associated with any chemical process. A temperature of many million degrees must be attained before nuclear fusion can start. Once started the reaction will proceed in an explosive manner with a very large evolution of heat because the internal energy of the helium atom is less than that of the two deuterium atoms.

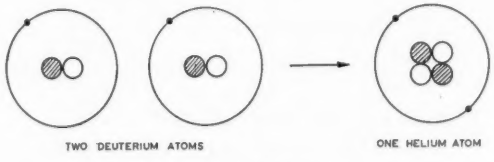


Fig. 3. A nuclear reaction.

This fusion reaction is typical of the kind of process which can take place inside a so-called hydrogen bomb. It may eventually be harnessed for the production of useful heat and power although the engineering difficulties are formidable in the extreme.

Natural radioactivity

Historically, our knowledge of the existence of nuclear energy dates back to 1896 with the discovery of natural radioactivity by Becquerel. Radium, which is found naturally in association with uranium salts, undergoes a slow transmutation into another element, radon, with the emission of helium nuclei or α *particles* (Fig. 4). Actually this is only one step in a long process of break-down; the final product, after several intermediate steps, is one of the stable isotopes of the chemical element lead.

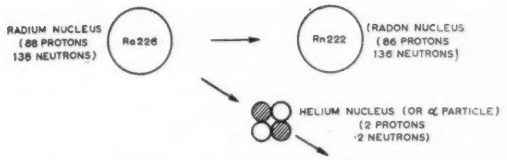


Fig. 4. Emission of alpha particles from radium.

Artificial radioactivity

The artificial transmutation of one element into another was first demonstrated by Rutherford in 1919. By bombarding nitrogen with α particles (Fig. 5) the isotope oxygen-17 was produced.

The next major step was taken in 1932 by Cockcroft and Walton who, by using artificially accelerated protons as the bombarding particles, were able to disintegrate the lithium nucleus according to the process represented in Fig. 6. Since this first experiment of Cockcroft and Walton a very large number of nuclear reactions have been achieved by bombarding different nuclei with high-energy particles. For this purpose large accelerating machines such as cyclotrons and synchrotrons have been constructed.

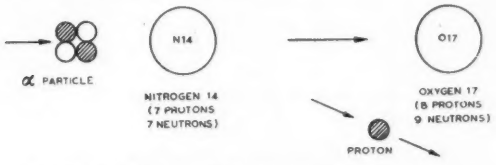


Fig. 5. Production of O17 by bombarding nitrogen with α particles.

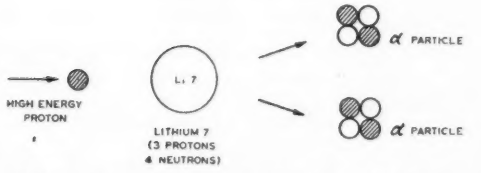


Fig. 6. Disintegration of lithium nucleus by artificially-accelerated protons.

Nuclear fission

A different type of nuclear reaction was discovered in 1939 with the fission of the uranium isotope U235. This is shown diagrammatically in Fig. 7. If an atom of U235 captures a neutron, it can break down into two more or less equal fragments or *fission products*. At the same time two or three neutrons are emitted and a considerable amount of energy is released in the form of heat. The important point

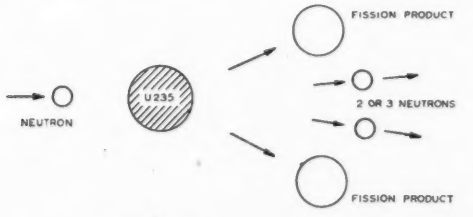


Fig. 7. Fission of the uranium isotope U235 by neutron capture.

to note is that the neutron which is the starting point of the process is reproduced in greater numbers at the end. A divergent *chain reaction* thus becomes possible.

The fissile isotope U235 occurs in natural uranium only to the extent of 0.7%, the remaining 99.3% being the non-fissile isotope U238. To construct an atomic bomb using uranium-235, therefore, it is necessary to carry out some process of physical separation of the isotope U235 from the more abundant isotope U238. Even with pure U235 available, a certain *critical size* is required before a chain reaction can occur because of the inevitable loss of neutrons from the surface. If any U238 is present with the U235, neutrons will be captured by the U238 to form the new element *plutonium*. This process is represented in Fig. 8.

The neutrons formed as a result of the fission of U235 are emitted at very high energy (see Fig. 7). High-energy neutrons are more readily captured by U238 than by U235.

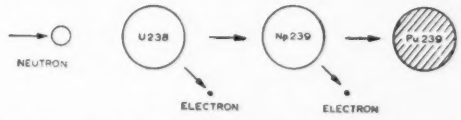


Fig. 8. Formation of plutonium from neutron capture by U238.

Partly for this reason and partly because of the much greater quantity of U238 present, a chain reaction is not normally possible in natural uranium. Slow neutrons (or *thermal energy* neutrons), however, are more easily captured by U235 than by U238. This fact provides the key to the operation of a controlled chain reaction using ordinary natural uranium. It is necessary to introduce another material known as a *moderator* in addition to the uranium. The purpose of the moderator is to slow down the high-energy neutrons by successive collisions until they reach the thermal-energy range where they are more likely to be captured by atoms of U235 and thus cause further fission. A good moderator must have light atoms which do not easily capture neutrons. Hydrogen, deuterium, beryllium, and carbon are some of the more suitable materials for use as a moderator. Hydrogen and deuterium are most conveniently used in the form of water and heavy water respectively. A nuclear reactor using uranium in association with a moderator is known as a *thermal reactor*. The controlled chain reaction is represented diagrammatically in Fig. 9.

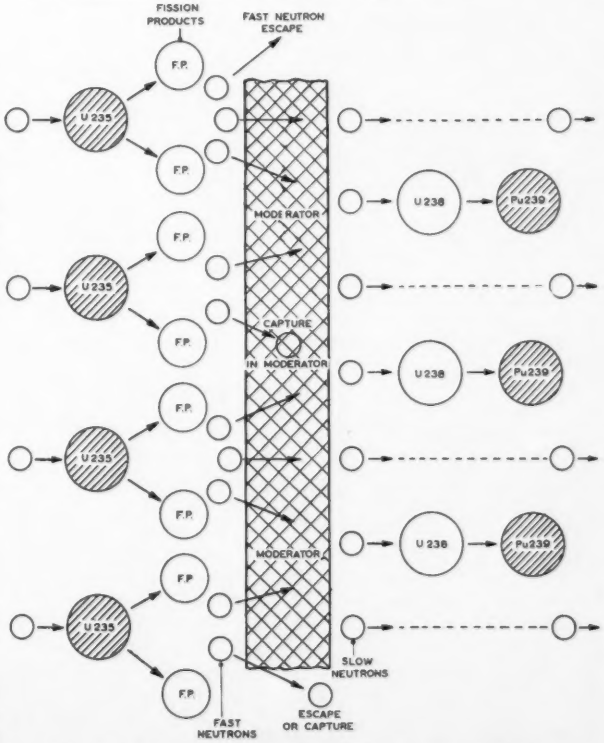


Fig. 9. Controlled chain reaction in a thermal reactor.

It can be seen that neutrons may be lost either by escape from the reactor core or by capture in the moderator or in other materials of construction used inside the reactor. Neutron economy is a matter of considerable importance in the design of any nuclear reactor. Materials have to be chosen with due regard to their nuclear physical properties in addition to the necessity of meeting stringent mechanical and chemical requirements. Just as in the case of a bomb, the core of a nuclear reactor must be of a certain minimum critical size to sustain a chain reaction. This size will depend on the choice of moderator, the design of the core, and on the proportion of the fissile isotope U_{235} which is present in the uranium fuel. Many reactors require the use of *enriched uranium*; that is, uranium having the proportion of U_{235} artificially increased above the figure which is found with natural uranium.

Thermal reactors may be divided into two main classes according to the way in which the uranium is associated with the moderator. In a *heterogeneous reactor* the uranium is usually employed in the form of solid fuel rods arranged in lattice formation and surrounded by the moderator. In a *homogeneous reactor* the uranium is dispersed in the moderator in the form of a solution; for example, when a compound of uranium such as uranyl sulphate is used in an aqueous solution with the water acting as the moderator. In the case of heterogeneous reactors, if metallic uranium is used as the fuel, it is necessary to enclose the fuel rods in protective sheaths or cans to avoid oxidation or corrosion of the metal and to prevent the escape of fission products.

It will be observed from Fig. 9 that, in addition to the production of heat which is required for power generation, there are two by-products from a nuclear reactor—plutonium and fission products. Plutonium, which is formed by capture of neutrons in the uranium-238 is of considerable value because it is a fissile material like U_{235}. The fission products, on the other hand, are not at present of any significant economic value and, because of their lethal character, they

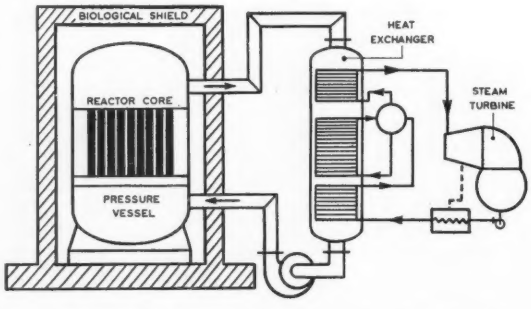


Fig. 10. Typical arrangement of reactor and electricity-generating plant.

constitute a special problem in disposal or storage. Irradiated fuel must be discharged from time to time and subjected to chemical processing in order to separate out the plutonium, the depleted uranium, and the fission products. The plutonium and the depleted uranium can then be re-cycled for further use as fuel.

The heat generated in a reactor core must be extracted by means of a *coolant* passing through channels inside the core. External heat exchangers can then be provided to enable the heat to be transferred from the coolant to the steam or other working substance of a power plant. A typical arrangement is shown in Fig. 10. The coolant circulated through the core may be either a gas such as air or carbon dioxide, water under pressure, or a liquid metal such as sodium.

About a dozen types of nuclear reactor are being studied for central power station use. There are several reasons for this diversity of approach. Availability of materials is one consideration which varies in importance in different countries; the U.S.A., for example, has a large stock of enriched uranium. One of the prime reasons, however, is the cost of the electricity produced. Present estimates of cost for a unit of electrical power from a nuclear station show that capital charges make a larger contribution than is the case with coal stations. There is therefore an incentive to treat capital charges as a major issue and thus to seek the type of reactor which can yield the largest amount of power from a given investment. This is a complex problem and the answer may well be different in different countries; a complete answer can be expected only after operational experience with the various types.

Principal types of reactor

Of the dozen or so possible types of reactor the following six may be regarded as being of special importance and are being actively developed in different countries.

The graphite-moderated, gas-cooled reactor, using natural uranium, is being built at Calder Hall and this type also forms the basis of the first stage of the U.K. power programme. Graphite-moderated gas-cooled reactors are physically of very large size but they offer the advantages of certain features of inherent safety and they can use ordinary natural uranium for their fuel. They may be expected to play a long and important role in the large-scale development of nuclear power.

The heavy-water-moderated and cooled type has been actively pursued in Canada. It shares with the graphite-moderated gas-cooled reactor the advantage of being able to use natural uranium, but suffers from the disadvantage of the very high cost and limited availability of heavy water.

The light-water-moderated, water-cooled type using slightly enriched uranium, known in America as the P.W.R. (pressurized water reactor), is probably the favourite runner for the first stage of nuclear power in the U.S.A. It requires enriched uranium, or a mixture of natural uranium and plutonium, for its fuel. Among the engineering problems involved are the use of high pressure plant and difficulties with corrosion.

The boiling-water reactor may be regarded as a development from the pressurized-water reactor. The heat exchanger is omitted altogether and steam is generated directly by boiling the coolant water inside the core. Difficulties may arise with the possible contamination of the steam turbine plant in the event of a fuel-element failure and carry-over of activity with the steam. Nevertheless the boiling-water reactor is regarded as a promising development for the future and appears to offer a higher degree of inherent safety than was originally expected.

Graphite-moderated, sodium cooled.—This is one of the possible types of liquid-cooled reactor which may play a prominent part in the second stage of the power programme. It will appear to the best advantage at very large power ratings and offers the possibility of higher temperatures and better steam conditions for the power plant. It again requires the use of slightly enriched uranium.

Fast reactor with sodium cooling.—The development of this type of reactor may be regarded as a long shot for the future. It holds out the prospect of the *breeding* of fissile material; that is, a rate of conversion of U_{238} to plutonium greater that the rate of fission of either U_{235} or plutonium. It requires a supply of highly enriched fuel and presents some very formidable engineering problems on account of the small size of the core. Experimental prototypes are being constructed at Dounreay in Scotland, and also in the U.S.A.

World News

The "Atoms for Peace Conference" of twelve nations in Washington completed its first session on March 21. Unconfirmed reports, including the possibility of a world conference in September in New York to be opened by President Eisenhower, have been issued, but a period has been given for members to report back to their countries for consultations before official announcements will be made. The Conference will reassemble on April 9.

It is generally understood that a large measure of agreement has been reached on many subjects. The international agency which will be set up will probably report back to the United Nations General Assembly although initially both Britain and the United States opposed this move. India is the chief objector to the suggestion that countries, notably the United States, giving fissile material should retain a measure of control over its usage. The United States is concerned that plutonium bred in reactors might be used for military purposes.

O.E.E.C. Action.—The first meeting of a special committee set up by O.E.E.C. was held in Paris on March 27. The Committee is required to submit proposals on the possibility of action in the field of nuclear energy within three months.

International declassification of some 10,916 research and development documents has been announced by the U.S.A.E.C. A team of scientists and engineers have recently completed a review of secret documents and have declassified approximately a third and arranged for a further third to be transferred to the "confidential" category.

The fifth World Power Conference which will be held from June 17-23 in Vienna will for the first time hear papers on the application of nuclear energy to power generation. The Government of the United Kingdom has appointed Sir Harold Hartley, K.C.V.O., C.B.E., F.R.S., President of the World Power Conference, as their official delegate. Sir John Hacking will be the official delegate from the British National Committee. The United Kingdom will submit five papers on subjects relating to nuclear power generation, the Netherlands one, Sweden one, United States seven, France one and Germany one. Approximately 400 people from the United Kingdom are expected to attend the Conference comprised of 225 full members and 175 observers.

GREAT BRITAIN

Civil Estimates.—It was disclosed in the civil estimates presented to Parliament on March 12 that expenditure on nuclear energy in the coming year will be £14 million more than last year's total of £54 million. Of £36 million to be spent on works, services and plant £2½ million will be for new works and more than £13 million for works already started. Among the new buildings will be a small outstation of A.E.R.E. at Grove Airfield, near Wantage, Berks. This station is intended to allow the technological radiation group which is part of the Harwell isotope division to develop more rapidly. Later it is proposed to transfer the Isotope division from Harwell to the new site.

D.S.I.R. grants to universities for costs of building and maintaining particle accelerators and for running costs of nuclear research in the year 1954-1955, totalled more than £2¼ million. Outstanding in this list is £617,000 for the Liverpool 400-MeV synchrocyclotron construction. Glasgow was granted £354,700 for constructional expenses for the 300-MeV synchrocyclotron.

Films.—A series of six coloured films is to be made by Mr. B. Charles Dean, as executive producer, to be entitled *British Atomic News*. The purpose of these films, which will receive the majority of their circulation abroad, is to demonstrate British manufactured products in the field of nuclear energy. It is understood that contributors in the first of the series will include Costain-John Brown, Morgan Crucible Co., L. M. Van Moppes and Sons (Diamond Tools), and Edwards High Vacuum.

Insurance problems in the field of atomic energy were discussed at a two-day conference organized by the Chartered Insurance Institute at Oxford last month. More than 170 senior insurance officials attended as well as a number of scientists from Harwell.

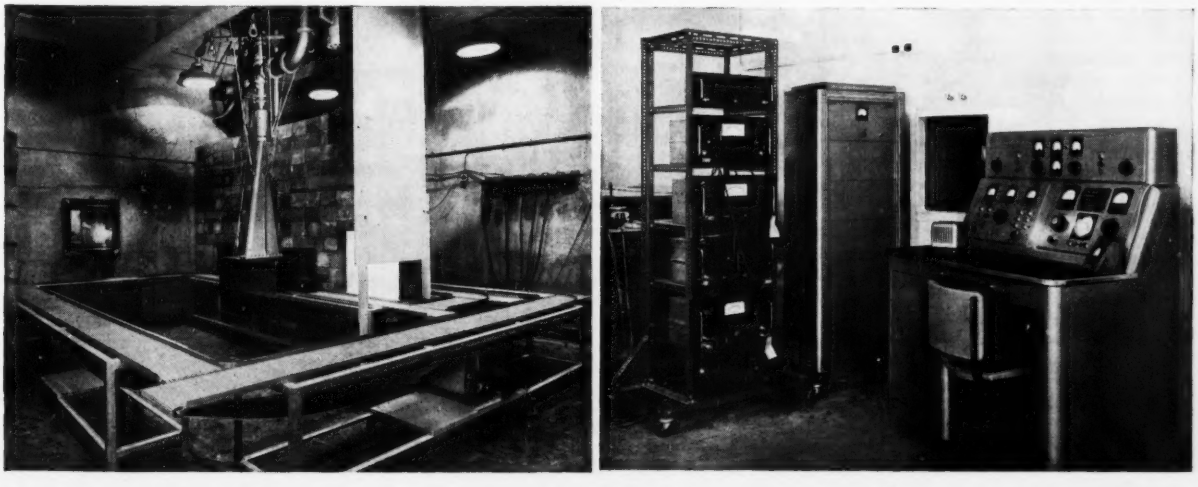
Acton Technical College is expecting to initiate in the next few weeks courses on nuclear physics to bring experienced engineers up-to-date with the progress in fundamentals of reactor technology. A grant of £1,200 has initially been received for the purchase of equipment, such as scintillation counters, ratemeters, but it is expected that when their new laboratories are completed next year that a further grant of £1,150 will be made available for nuclear engineering equipment. Courses will then be run both full-time and part-time on reactor engineering.

AUSTRALIA

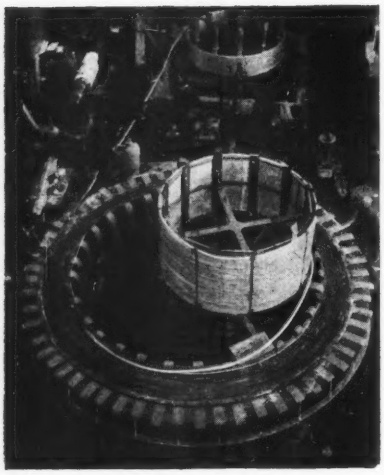
Uranium for Britain.—The U.K.A.E.A. has entered into a contract with Mary Kathleen Uranium Ltd. to buy uranium concentrates to be produced in the Mary Kathleen mine in north-west Queensland. This company is a member of the Rio Tinto group of companies. The Authority has undertaken to lend up to £5 million to bring the mine into production; the remainder of the capital is to be found by Rio Tinto who are providing up to £2½ million for this purpose.

The mine is situated some 500 miles from the coast at Townsville and about 40 miles from Mount Isa. The ore is pitchblende associated with allanite, being a complex rare earth deposit of a type which has not hitherto been mined for uranium.

High Temperature Reactors. — Before returning to England Professor Watson-Munro recently stated in Canberra that research on high-temperature reactors started in England by Australian scientists would be continued in Australia when the Commission's laboratories at Lucas Heights, near Sydney, were completed. He forecast that Australia will within five to fifteen years develop their own atomic power services.



Technological irradiation facilities at Tube Investments Research Laboratory, Hinxton Hall, Cambridge. On the left is the irradiation cell showing the beam tube of the 2-MeV Van de Graaff. Samples can be passed underneath on remotely controlled conveyor belts. On the right can be seen the control cabinet for the generator and a rack of standard nuclear measuring equipment.



Winding the first coil of the synchrocyclotron magnet for C.E.R.N. at the works of Ateliers de Constructions Electriques de Charleroi. The second half has recently been delivered to Geneva.

CANADA

Uranium Production.—Canmet Explorations report an offer from Eldorado Mining and Refining—a Crown company responsible for producing and purchasing all radioactive raw materials—providing for the sale of its output of uranium oxide concentrates to the value of nearly $70 million. The contract is based on a mill capacity of 2,500 tons daily and the scheduled starting date is April 1, 1957. Drilling at the company's Blind River, Ontario, site has indicated an ore body of over 5 million tons with a grading of 0.1% uranium oxide.

Uranium in Labrador.—Two companies, the British Newfoundland Corporation and Frobisher Ltd., of Toronto, have discovered uranium in Labrador.

CEYLON

U.S.A. Offer.—The United States has offered Ceylon an atomic reactor and fissile material for research and training purposes. It is understood that if it is accepted the reactor would be operated under the auspices of the Ceylon University.

CHILE

Exploitation of Uranium.—There are 12 known uranium deposits in the northern province of Atacama. The quality varies considerably but the best samples were equal in quality to the highest in the world. Making this announcement Senor Carlos Ruiz, Under-Secretary of Mines, also stated that the Anaconda Copper Mining Co. of America was studying the possibility of building a nuclear power plant in Chile.

EIRE

Research co-operation between the U.S.A. and Eire has been agreed. Under the agreement, signed in Washington by the Eire Ambassador, Mr. John Hearne, and the Deputy Assistant Secretary of State, Mr. C. Burke Elbrick, Eire will receive non-classified information on research reactors, related health and safety problems and the use of radio-isotopes. The U.S.A. will lease to Eire up to 6 kg. of contained uranium-235.

FRANCE

G.4.—The high commissioner for atomic energy, M. Francis Perrin, has revealed that G.4 will be built in Algeria and that a nuclear research institute will be set up in Grenoble. He has also announced that the facilities of the arsenal at Cherbourg will be used for work on nuclear propulsion for ships.

E.D.F.I.—The first French nuclear power station, to supply 60 MW, will be built in the Val-de-Loire district. It will use plutonium produced at Marcoule, and is scheduled for completion in 1959. Owned by Electricité de France, it will be known as E.D.F.I.

EGYPT

Russian Offer.—Following the recent establishment in Cairo of a radioactive isotope centre, purchased from the United States, Egypt is now considering a Russian offer to help set up a nuclear physics laboratory. According to the announcement Soviet specialists will be sent to Egypt to advise on the planning and construction of the laboratory, whilst Egyptian technicians will go to Russia to study relevant methods.

GERMANY

European Atomic Energy Society.—The West German Atomic Energy Ministry has joined the European Atomic Energy Society at the invitation of the Society's president, Sir John Cockcroft. Prof. Werner Heisenberg, director of the Max Planek Institute for Physics, Grettingen, will be the chief German delegate.

British Offer of Assistance.—The British Ambassador, Sir Frederick Hoyer Miller addressed about 1,000 business men at Uberseeklub, Hamburg, recently on British plans for the peaceful uses of atomic energy. He offered the Germans collaboration on the building of power reactors and the training of engineers at the Harwell reactor school.

GREENLAND

Finds of uranium and thorium have been reported in the areas near Skovfjord, Tunugdliarfik Fjord, and Kagssiarssuak near the Narssasswak base.

HOLLAND

An international atomic energy exhibition will be held near the Schipol airport, Amsterdam, next year. The Amsterdam municipal authorities will contribute about £600,000 toward the cost.

INDIA

Heavy Water Project.—The Indian Atomic Energy Department has engaged a British company, Costain-John Brown Ltd., to report on heavy-water production at Nangal and other places. The company will be paid a fee of £31,000 for the report. The scheme will form part of the Bhakra-Nangal dam project which includes the generation of electric power and the operation of nitrogen fertilizer factories.

ITALY

Prospecting for uranium is being carried out by the State National Committee for Nuclear Research and by private mining companies. In the southern Alps of Piedmont several thousand tons, having a uranium content of three to six parts in a thousand, have been mined. The Montecatini group have mined a small deposit in the province of Cuneo, Piedmont.

JAPAN

Nuclear Power Programme.—Japan is seeking agreements with Britain and the United States for the development of nuclear power. The authorities of the newly formed Atomic Energy Commission are reported to be interested in the Calder Hall type of reactor because of its simplicity and safety. Whilst Japan is obtaining her first nuclear power equipment from the United States tentative approaches to British manufacturers have been made, say reports.

A spokesman of the Atomic Energy Bureau of the Prime Minister's office said that a water-boiler research reactor has been ordered from the U.S.A. A CP-5 reactor for isotope production is also on order. He also added that a 10,000 kW natural uranium heavy-water-moderated reactor would be built in 1958 by Japanese technicians.

Fourth Cyclotron.—Due for completion this month is Japan's fourth and largest cyclotron which is being built by the Tokio Shibaura Electric Co. Ltd. for the Tokyo University's research laboratory at Tanashi. It will be capable of accelerating protons up to 60 MeV and deuterons up to 21 MeV.

NORWAY

Dutch-Norwegian Group Progress.—Dr. Gunnar Randers, Director of the Joint Establishment for Nuclear Energy Research in Norway, recently stated that the Dutch-Norwegian group would have at its disposal four reactors in two years. These are:

1. The existing reactor at Kjeller, which at present is being equipped with heat exchangers for about 800 kW.
2. The steam producing heavy water boiling reactor at the paper pulp factory at Halden; this reactor is expected to be ready before the end of 1957, if no unexpected obstacles appear.
3. The slurry experiment in Arnhem, Holland, expected to be running within a year.
4. A materials testing reactor of the Oak Ridge type to be bought by the Netherlands from the U.S.A.

Dr. Randers has also indicated that Kjeller is supplying radio-isotopes to many countries. New production methods have been worked out which represent a considerable simplification on those used in Britain and the U.S.A. He instanced the production of radioactive phosphorus with high specific activity.

Nuclear-Powered Merchant Ship.—Following a visit to the Kjeller establishment, Prof. R. Fayram, of the University of California said that Norway may be able to launch a nuclear-powered merchant ship within three to five years.

PAKISTAN

Research.—The Government has formed an Atomic Energy Council to plan and establish nuclear research institutes. The Council will control the supply, manufacture and disposal of radioactive materials and will carry out mineral surveys. It will be headed by the Minister of Industries, Mr. Habib Ibrahim Rahimtoola.

PHILIPPINES

A nuclear research centre costing £7 million is to be established in the Philippines and will be financed by the United States $100 million fund for Asian economic development. Detailed plans are expected to be presented at the Colombo Plan meeting in New Zealand next October.

The centre will have laboratory facilities and a reactor for research and training, and its major purpose will be to provide training for instructors and technicians in nuclear science for other Asian educational institutions.

SPAIN

Power Station Plans.—Reports from Madrid suggest that Sociedad Hydroelectrica Iberica and Electrica de Viesgo S.A. are contemplating the building of a nuclear power station at Bilbao.

SOUTH AFRICA

Exports.—During the first eleven months of 1955 South Africa exported uranium and thorium to the value £26 million. This is double the figure for 1954.

Power for Mining Concerns.—Shortly after the announcement of the tie-up between Mitchell Engineering Ltd. and the American Machine and Foundry Atomics Inc. of New York, Mr. F. G. Mitchell, chairman of the British company, announced that two of South Africa's biggest mining corporations are examining the possibility of the purchase and operation of a nuclear power plant.

A nuclear physics research unit has been set up in the Department of Physics of the University of the Witwatersrand. This unit has been established as a result of a gift of £15,000 per year for seven years from the South African diamond and gold mining industries. In addition to this gift the diamond mining industry has agreed to give the University access to the 2 MeV particle accelerator which is to be installed at the Diamond Research Laboratory, a few miles from the University. The unit will also have access to the cyclotron which has recently been brought into use at the National Physical Laboratory in Pretoria about 40 miles away.

In announcing the University's acceptance of the offer Professor W. G. Sutton, principal, said that the value to South Africa of the supply of trained nuclear physicists that would follow the establishment of a school of nuclear physics would become evident in a number of ways, principally through the use of radioactive isotopes in research in industry, medicine and agriculture, and through the possibility that the Union of South Africa would extend its activities beyond the production of uranium oxide.

SWEDEN

Asea-North American Link-up.—Discussions took place in Stockholm recently between representatives of Atomic International, a division of North American Aviation Inc., and Asea, a leading Swedish electrical concern with works at Vasteras, near Stockholm, with a view to co-operation between the two firms. The exact purpose of the negotiations has not been disclosed, but it is suggested in the Swedish Press that co-operation might lead to an export industry being established.

Atomics International is constructing a sodium-cooled graphite-moderated experimental reactor of 20 MW heat capacity, which is now due for completion.

THAILAND

American Aid.—The United States Secretary of State, Mr. John Dulles, and the Thai Foreign Minister, Prince Wan Waithayakon, signed an agreement on March 13 under which the U.S.A. will help Thailand to develop atomic energy for peaceful purposes. An experimental reactor will be built. The agreement also provides for the supply of radio-isotopes for use in medicine and agriculture, and an extensive nuclear library and the services of a member of the United States A.E.C. for the advice and training of Thai scientists.

U.S.A.

Heavy Water Supplies.—Six nations will receive a total of 129 tons of heavy water to help them in their peaceful uses of atomic energy, it was announced in Washington last month. Britain will receive 50 tons, France 30 tons, India 21 tons, Australia 11 tons, Italy 10 tons, Switzerland up to 7 tons with 2 tons to be delivered after August, 1957.

Of the first shipment totalling 16 tons 11 have been sent to Britain and 5 to France. The price is $28 per lb.

Navy Plans. — According to Rear-Admiral W. K. Mendenhall, chief of the U.S. Navy's fleet development and maintenance division, the atomic-powered submarine Nautilus has proved so successful that the United States will probably end production of conventional submarines after this year. Last month the keel was laid for the navy's fifth nuclear-powered submarine and ten more are in the active planning stage. The U.S. Navy has also drawn plans for the building of a cruiser and a 70,000-ton aircraft carrier to be powered by nuclear energy.

Minerals Agreement.—Two large American concerns, Crane Company and Vitro Corporation, have entered into a joint agreement to produce thorium, rare earths and heavy minerals from monazite as well as rutile, ilmenite, zircon and kyanite. Under this agreement the two companies will assume equal ownership of Heavy Minerals Co. and its subsidiary Marine Minerals Inc. A subsidiary of the French chemical group of Pechiney continues to hold a minority interest in Heavy Minerals Co. which has an exclusive licence to numerous patents held by the French company on the processing of thorium, rare earths and heavy minerals.

South American Development.—American and Foreign Power, the company which operates electricity utilities in eleven Latin-American countries, is now considering tenders received for three 10,000-kW nuclear power plants. The company hopes to select three different types of plant. It is understood that about six companies tendered.

Standardization.—Industry and government officials, 175 strong and representing most groups concerned with nuclear radiation, met in Washington recently and agreed to call on the American Standards Association for the constitution of a "planning committee of experts". This body of 10 to 15 will study the need for standardization in the nuclear field, stake out and delimit the problems, and report back to the industry-government conference. They are to consider the effects of radiation on both people and materials. They may also recommend whether a new Nuclear Standards Board should be established within ASA to supervise the work of drawing up standard codes.

The American Nuclear Society which has a membership of over 1,000 is establishing its headquarters at Oak Ridge, Tenn. The address of the executive secretary is P.O. Box 963.

The society is running a 50-week training programme in nuclear reactor engineering at Oak Ridge School of Reactor Technology.

A school of Nuclear Science and Engineering for the Atomic Energy Commission of the United States, is operated by the Argonne National Laboratory, Lamont, Illinois. The school is unclassified, so that it can accept students who are citizens of countries other than the United States.

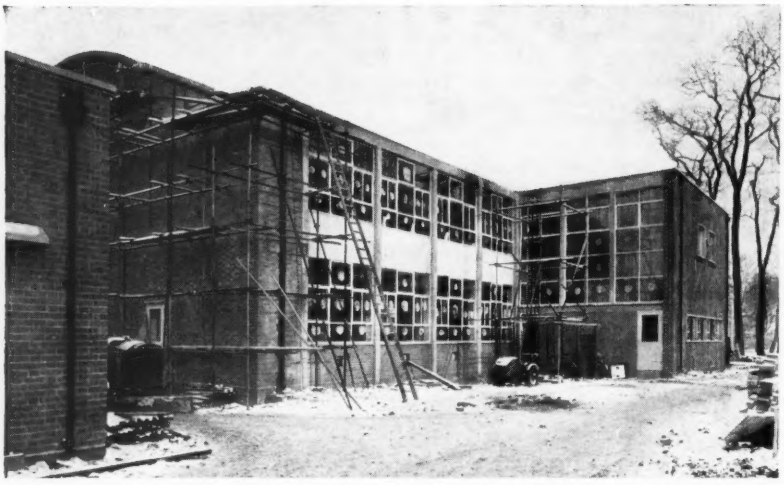
U.S.S.R.

Five-Year Plan.—Reports from Russia indicate that the current five-year plan which began this year will include the broad development of nuclear power for aviation, land transport and marine use. An announcement has been made that Russia will build an 11,000-ton icebreaker using atomic propulsion, the fuel requirements being about 200 grammes per day. According to Prof. G. Pokrovsky the vessel would not only be used as an icebreaker but as a floating power station which could supply electricity to posts and settlements on the Arctic coast.

Tass, the Soviet news agency, reports that a 400 MW nuclear power station to supply the Moscow region would be built by 1960, and would play an important part in the electrification of the suburban railway system.

Eastern Research Institute.—The organization of an Eastern nuclear research institute was the subject of a conference begun in Moscow on March 20. Representatives from Czechoslovakia, Albania, Bulgaria, Eastern Germany, Hungary, Communist China, North Korea, Mongolia, Poland, and Roumania attended the conference.

The use of radio-isotopes and tracer atoms in the oil industry formed the subject of a conference which opened in Moscow on March 14.



Rolls-Royce work on the application of nuclear energy to aircraft propulsion and related fields will shortly be supplemented by the completion of this nuclear engineering laboratory.

Trade Notes

New Nuclear Group.—Vickers Ltd., Rolls-Royce Ltd. and Foster Wheeler Ltd. have formed a group to work on nuclear energy. For this purpose a new company, Vickers Nuclear Engineering Ltd. has been formed with Sir Ronald Weeks, Lord Hives, Major-General C. A. L. Dunphie and Mr. G. H. Hopewell as directors. Rear-Admiral L. E. Rebbeck will be in charge of projects, the first of which will be the application of nuclear energy to marine propulsion.

A 2-MeV Van de Graaff particle accelerator is being installed by British Insulated Callender's Cables Ltd. at their research laboratories at 38 Wood Lane, London, W.12. It will be used for research into the effects of irradiation on materials used in cable and capacitor manufacture. The installation is being carried out by High Voltage Servicing Co. Ltd.

Isotope Developments Ltd. have announced that A.E.I. Ltd. have agreed to take up the majority of their new capital share issue. This will give A.E.I. a 50% holding in the company. Mr. N. R. Davies, managing director of Sunvic Ltd., has joined the board. Due to the resignation of Mr. R. Peters, Mr. W. Hill-Wood, executive director of Morgan Grenfell and Co., Ltd., has become chairman. Mr. G. F. Thick and Mr. H. A. Luss have been appointed joint managing directors.

Plessey Nucleonics Ltd., a recently formed associate of the Plessey Co. Ltd., Ilford, Essex, is to specialize in the development and production of all forms of control equipment and systems, as well as special instrumentation.

E.M.I. Electronics Ltd., Hayes, Middlesex, are now the sole selling agents at home and overseas for the quantity-produced instruments made by Industrial Electronics, Magnet Works, Derby Road, London, S.W.14. These include the model 2300 oscilloscope and the model 1950/2 A.F. panoramic analyser.

To stimulate research in the mechanical and electrical aspects of power generation, control and utilization, Brush Electrical Engineering Co. Ltd., of Loughborough, has established a senior research fellowship within the Applied Science Faculty of the University of Nottingham with an annual value of between £600 and £750. This award is open to all honours graduates in science or engineering.

A permanent display of scientific instruments and an extensive catalogue library has been established at the headquarters of the Scientific Instrument Manufacturers Association of Great Britain, at 20 Queen Anne Street, London, W.1. The display will be changed periodically so that all 140 member companies will be able to take part.

An order for 3.3-kV, 150-MVA air-break switchgear, to the value of £230,000 has been received by the British Thomson-Houston Co. Ltd. for the Capenhurst works of the U.K.A.E.A. This is a repeat of an earlier order now nearing completion.

Fuel-Element Production.—A $1½ million factory-expansion programme is in hand for the nuclear products division of the Metals and Controls Corporation of Attleboro, Massachusetts, U.S.A. It will enable the division to step up production of fuel elements and components.

New research laboratories are to be built by Mervyn Instruments, Copse Road, St. John's, Woking, Surrey. The research team is under the direction of Mr. K. G. Dobson who was responsible for the design of the Mervyn infra-red spectrometer and the automatic data handling equipment.

A short course on the elements of radiological protection will be held at the Isotope School, A.E.R.E., Harwell, from April 9 to 13. The course will consist of lectures and practical work and will be attended by industrial users of radioactive isotopes.

A special mill for rolling uranium has been ordered by the Swedish Atomic Energy Authority from W. H. A. Robertson and Co. Ltd., Bedford. This company built the first mill of this kind in Britain and now has a number in production for the U.K.A.E.A.

The S.E. London Technical College, Lewisham Way, is to begin a short course of six lectures on atomic energy subjects on May 2. The lectures will be given by Mr. W. P. Jolly and the fee will be 10s.

Dowty Nucleonics Ltd. is now located at Brockhampton Park, Andoversford, Glos., where a team of about 80 specialists are now working under the direction of Mr. T. D. H. Andrews, A.M.C.T., A.M.I.Mech.E., A.F.R.Ae.S. The electrical division of Dowty Equipment Ltd. has been incorporated in the new set-up and the Tewkesbury works becomes the production factory for Dowty Nucleonics Ltd.

Personal

Sir Ben Lockspeiser, K.C.B., F.R.S., retired from the post of secretary to the Committee of the Privy Council for Scientific and Industrial Research on March 10. His successor is **Professor H. W. Melville,** F.R.S., who occupies the Mason Chair of Chemistry at the University of Birmingham. He will take up his new appointment in August.

Professor G. W. O. Howe, D.Sc., LL.D., M.I.E.E., who is Emeritus Professor of Electrical Engineering at the University of Glasgow and a director of the Mullard Radio Valve Co. Ltd., is to receive the 34th award of the Faraday Medal which is awarded by the Council of the Institution of Electrical Engineers, London.

Mr. Lawrence H. A. Pilkington, senior technical director of Pilkington Brothers Ltd., and chairman of the British Glass Industry Research Association is to be conferred with the Honorary Degree of Doctor of Laws by Sheffield University.

Mr. Walter Zinn, director of the Argonne National Laboratory since its establishment in 1946, has resigned.

Mr. J. K. Weir, chairman of the Weir Group of companies, has resigned as joint managing director of G. and J. Weir Ltd. **Mr. J. Russell Lang** has been appointed sole managing director and **Sir Charles Connell** an additional director.

Mr. William E. Jenkins has retired from his position of managing director of the Esso Petroleum Co. Ltd. **Mr. H. C. Tett** and **Mr. R. J. Pinder** have been appointed managing directors. **Mr. C. Chilvers,** manager of the co-ordination and economics department, has been appointed to the Board.

Mr. Stanley F. Steward, managing director of Lancashire Dynamo Holdings Ltd. has been made a director and chairman of the Board of Lancashire Dynamo and Crypto Ltd., a member of the Lancashire Dynamo Group. **Mr. A. W. A. Dick-Cleland** and **Mr. D. C. Lorkin** will continue as joint managing directors.

Mr. J. K. Batty, joint managing director of the Alkali Division of Imperial Chemical Industries Ltd., has been appointed chairman of the Division in succession to **Mr. W. M. Inman** who has retired.

Mr. Gilbert Way, manager of the general sales division, Dunlop Rubber Co. Ltd., Fort Dunlop, succeeds **Mr. E. F. Mitchell** as the company's sales manager for the Midlands.

Mr. Sam J. Farmer, division counsel of the Electric Boat Division of General Dynamics Corporation, has been appointed to a similar position with the Corporation's General Atomic Division.

Mr. William Gervine, counsel for the Division of Military Applications of the United States Atomic Energy Commission, will succeed him at Electric Boat.

Mr. James Segre, business and technical consultant in Milan, Italy, has been appointed European representative for Allen B. Du Mont Laboratories Ltd.

Dr. H. Seligman, head of the Isotope Division, A.E.R.E., Harwell, left on February 17 for an extended tour of nuclear establishments in the U.S.A. He will be returning in early April.

Dr. J. L. Putman, of A.E.R.E., Harwell, was among the guests attending a five-day meeting of German nuclear scientists in Aachen. The conference, which opened on March 7, was to discuss aspects of radio-isotope research.

Technical Papers and Publications

B.N.E.C.

A symposium on Nuclear Energy under the auspices of the Institution of Mechanical Engineers in conjunction with the British Nuclear Energy Conference was held at the Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1, on March 28, 1956. Four papers were presented and were then followed by a discussion.

Due to difficulties in the printing trade advance copies of these papers were not available at the time of going to press. The majority of the information therefore which follows has been taken from the March issue of the *Chartered Mechanical Engineer.*

Nuclear Reactors for Power Generation

by B. L. Goodlet, O.B.E., M.A., M.I.Mech.E., M.I.C.E.

The paper outlines the problems encountered in the design of nuclear reactors for power generation. In the first part these problems are subdivided into reactor physics, reactor materials, radiation and radioactivity, and engineering design.

Reactor physics is concerned with the establishing and controlling of the chain reaction and hence with neutron economy. Reactor materials differ from normal constructional materials in that they must withstand radiation damage and induced radioactivity; the nuclear properties must be consistent with the physics of neutron economy and at the same time chemical compatability and good high temperature characteristics are required.

Due to the dangerous nature of the radiations from reactors, special measures must be taken for shielding and for containment and contamination must be avoided.

Engineering design is concerned with the production of fuel elements, the mechanics of the reactor core and with the various heat transfer problems associated with primary and secondary coolants. Many additional engineering problems are met in the design of tanks, foundations, remote handling equipment and so on.

As a result of these various considerations the paper demonstrates how the general forms of the various types of reactor, were derived with particular reference to the fast reactor, the pressurized water, boiling water and graphite-moderated reactors. After a discussion on heat removal and fuel element design an elementary section follows on control showing the manner in which the various units of a power plant are inter-connected.

The author recommended that the Appendix on Reactor Theory which covers in language comprehensible to engineers the basic physics on which reactor operation depends be studied first. Topics covered included nuclear collision cross-sections, fission chain reactions, lattice reactory theory, theory of homogeneous thermal reactors, temperature effects and poisoning after shut-down, etc.

Steam Cycles and Nuclear Power Plant

by R. E. Zoller, B.Sc., A.M.I.Mech.E.

Water-Cooled Reactors

Engineers welcome water as a pile coolant but physicists object to the neutron absorption of light water which calls for fuel enrichment. Heavy water does not have this disadvantage, but is expensive. When the fuel lattice arrangement is designed for a moderator density equal to that of hot water the coolant must be pressurized until the saturation temperature corresponding to water boiling at the coolant pressure is greater than the film temperature at the can surface; otherwise steam will be formed around the fuel element and the loss of moderator will upset the control.

An analysis of the conditions, at the point in the fuel-element channel where the maximum film temperature adjacent to the fuel element occurs, enables curves to be drawn showing the temperatures of the inlet and outlet water for different fuel ratings and pumping power.

The coolant temperature from the pile sets a serious limit on the maximum steam temperature that can be obtained. With light-water coolant pressurized to 1,000 lb. per sq. in., the stop-valve conditions might be 344 lb. per sq. in. saturated, and when steam at these conditions is expanded in a modern turbine down to a pressure of 28.5 inches of mercury vacuum, the moisture in the low-pressure stages produces high shock losses and causes heavy erosion. There is insufficient temperature head available for superheating with heat from the pile, and other methods of combating this problem have to be sought. Suggestions are made in the paper of possible methods of water extraction and reheat and the installation of separately fired superheaters is also discussed.

Many advantages are gained by superheating with oil because a conventional, separately fired, superheater will raise the stop-valve temperature to 900° F. or higher, and the turbine performance is much improved with the higher available heat drop and the lower moisture losses. This use of oil in Great Britain needs careful consideration because it increases the electrical output of the turbine with a small initial expenditure while the operating efficiency of the oil-heated cycle is very high.

The characteristics of a heavy-water-cooled pile are similar except that the stop-valve pressure may be lower owing to the greater diameter of the pile core restricting the operating pressure of the containing vessel.

Gas-cooled Reactor

When a change is made to gas cooling the differences in physical properties of the coolant change the steam cycle materially. The lower specific heat and density of the gas increase the circulating power. The pile is now pressurized for a different reason; the greater density directly reduces the blower power.

Optimum single- and double-pressure steam cycles for such conditions are derived in the paper. The gas flow may be chosen within wide limits, and as the basic blower power is high there is much scope for varying the blower power in relation to the main turbine output.

In general, with double-pressure steam cycles the problem of excessive exhaust moisture does not arise, but the adoption of oil-fired superheaters may be justifiable on economic grounds as mentioned with water-cooled reactors. The addition of the separately fired superheater allows the total heat release of the pile to be utilized in generating a higher evaporation. The boiler operating pressures are also higher.

Liquid-metal Reactors

Various metals and alloys have been suggested for cooling atomic piles and these have the advantage that although they operate at a high temperature their vapour pressure characteristics permit the circuits to be nominally at atmospheric pressure. Sodium and sodium-potassium alloys may be pumped at high temperatures with electro-magnetic and centrifugal pumps, thus the boiler may be designed with high coolant return temperatures.

Sodium and potassium become radioactive and a secondary circuit must be inserted between the pile and the boiler. The temperature loss in the intermediate heat exchanger might be small because with liquid metal on each side of thin tubes a very high heat-transfer rate is obtained.

Although very high steam pressures are possible, these would require such expensive boilers that a simple steam cycle with moderate pressure and high superheat is recommended.

Boiling-water Reactors

There have been several investigations into the use of flash steam from a pressurized water system but the pumping power would be very great when the water was being returned to the pile from the flash box. Then experiments showed that boiling water in the pile itself was capable of being controlled. The steam might pass direct to the turbine which would need protection against blade erosion by moisture extraction or separate superheating. Steam from a boiling pile must have no entrained salts that may be radioactive, otherwise the turbine will need heavy shielding and washing before overhaul. The pile makes use of water as a moderator and therefore the density of the steam-water emulsion has to be kept under control. A high moderator density will be required and thus in a forced-circulation system, large circulating pumps will be needed to maintain a high circulation ratio around the core.

Flashing off into a heat exchanger may be used for homogeneous reactors with the returns being gravity fed to the reactor. This is convenient when both the core and a breeder blanket work at the same pressure.

Discussion

Comments are made on the design of certain heat exchangers and also on the control of gas-cooled piles at part loads. The merits of steam-turbine drives for such piles are also mentioned.

In conclusion, attention is drawn in the paper to the fact that thermal efficiency in itself is not a good criterion when a comparison is made thereby with coal-fired stations. For example, the thermal efficiency of the steam cycle in atomic plants has the advantage that there are no boiler losses that are often debited against the normal station efficiency. The main factor to consider is the price to generate 1 kW-hr. and this may be reduced by sacrificing thermal efficiency for greater plant output; no general conclusions may be drawn from conventional stations because the initial and running costs are different proportions of the total cost.

Heat Removal from Nuclear Power Reactors

by Professor Jack Diamond, M.Sc.(Eng.), Wh.Sc., M.I.Mech.E., and W. B. Hall, B.Sc.(Eng.), A.M.I.Mech.E.

At the present time the only practicable way of converting into useful power the energy released by nuclear fission in uranium and plutonium fuels is by way of a heat-engine cycle. When a fission chain reaction takes place within a nuclear reactor, most of the energy released flows from the fuel as heat and its transfer to the working fluid of a heat engine is usually accomplished by the circulation of a coolant, first past the fuel elements in the reactor and then through a heat exchanger where the energy is transferred to the working fluid. The coolant is then introduced again into the reactor.

In reactor systems in which the fuel is in the form of solid rods or bars, the energy must be conducted within the fuel to its surface, transferred from the surface by forced convection into the coolant and transferred by the coolant from the reactor; the fuel must have the highest temperature in the system and energy must be absorbed by the forced-convection process.

It is generally true that the limitation on the rate of heat release in a reactor is the rate at which the energy may be removed continuously by the cooling system. For reasons of economy it is desirable to extract and use the energy from each unit of fuel at a high rate and this points to high coolant temperatures, so that the engine efficiency is high, and to a sufficient temperature difference for high heat transfer between the fuel and the coolant. With a metallurgical limitation on fuel temperature these two requirements conflict to a degree which depends on the coolant employed, the mass-flow rates permitted by frictional power consumption and the areas for heat transfer and heat transport permitted by nuclear design. Gas coolants must be pressurized to increase their densities and to diminish the frictional losses for a given mass-flow rate; fuel-element heat-transfer surfaces must be increased where possible by such means as extended surfaces. With liquid coolants the heat-transfer problem is less serious, although their use can involve special problems of corrosion, neutron absorption, radioactivity, and, as in the case of water, high pressures.

The cooling problem in a nuclear reactor cannot be dealt with in isolation. The coolant employed can have a profound effect upon the design of the entire reactor system; it is frequently the case that the nuclear design or the available fuel limits the choice of coolants and the way in which fuel heat-transfer surfaces may be disposed. The heat-transfer design of a nuclear reactor must be conducted within such limitations.

The paper describes the general problem of heat removal from reactors with solid-fuel elements and introduces the methods commonly employed for a first analysis of the heat-transfer design. With a gas-cooled reactor as an example, the authors discuss the influence of such factors as the size and shape of the coolant channel and of the fuel rod and the physical properties of the coolant. With gas cooling, extended surfaces are shown to be essential. In a numerical example in an appendix, the methods are illustrated by means of which a balance is achieved between the heat-transfer and nuclear-design parameters. Also described in appendices are the basic relationships governing the temperature distribution in the reactor, the pressure drop of the coolant and the power absorbed in its passage through the reactor channels. From the aspect of heat transfer, the high volumetric specific heats for liquids make them much better coolants than gases, but heat transfer is not the only consideration. The possibility of corrosion is greater with liquids and their greater density brings in considerations of neutron absorption within, and radioactivity without, the reactor.

The effect of Prandtl number on the forced-convection heat-transfer characteristics of a coolant is discussed and the essential differences between liquid metals and water in this respect are mentioned.

Water may be used as a coolant and as a moderator: light water requires fuel enrichment; heavy water, which is expensive, permits the use of natural uranium fuel. Two water-cooling methods have been developed: without change of phase and with net steam generation within the reactor. The condition of surface or nucleate boiling without net steam generation is discussed briefly.

The cooling problems of nuclear reactors are not confined to the removal of heat from the fuel. Any material in a reactor is heated, owing to gamma and neutron radiation, to a degree which depends primarily on its density, neutron cross-section and position in the reactor. Thus in the heat-transfer design of a reactor provision must be made for the cooling of the moderator and shield and other items such as control rods and structural materials.

Shielding Against Nuclear Radiation

by C. E. Iliffe, M.A., M.I.Mech.E.

Neutrons form one type of constituent particle of atomic nuclei. The intensity of neutron radiation at any point is expressed by means of the "flux" which is the rate at that point at which neutrons travelling in a certain direction cross unit area normal to this direction, summed over all possible directions. Owing to collision with atomic nuclei, neutrons may be scattered or absorbed. The probability per unit distance travelled by a neutron of its undergoing any such reaction is called the "cross-section." The rate at which neutrons undergo any such reaction in unit volume of material is given by the product of the cross-section and the flux, and the absorption cross-section times the flux= the rate at which the lowest energy or thermal neutrons are absorbed in unit volume.

The scattering process is treated by introducing the "net current density" which is the rate at which neutrons having a component of velocity in the direction x, pass from one side to the other of unit area normal to direction x less the rate corresponding to the opposite direction. Neutrons of sufficiently low energy obey Fick's law of diffusion.

An expression can then be derived for the thermal neutron flux in terms of "diffusion length," and the rate per unit volume at which higher energy neutrons are slowed down into the thermal group by successive collisions in the moderator and fuel elements.

Similar considerations apply to the highest energy, or "fast" neutrons. The absorption cross-section for fast neutrons is relatively small so that fast neutrons generally disappear through being slowed down sufficiently to become members of a lower energy group, which is the thermal group in a "two-group" treatment.

The two-group diffusion theory outlined above may be applied, with appropriate boundary conditions, to give the variation in fast and thermal neutron flux through the thickness of a slab of material. The theory is not highly accurate, however, as applied to neutron shielding problems, and experimental verification is necessary.

Gamma Rays

Gamma rays are transmitted in small quanta or "photons" of high-frequency electromagnetic radiation. The concepts of flux, current density and cross-section apply to gamma rays as to neutrons. Gamma-ray scattering however is markedly anisotropic so that, instead of diffusion theory, use is made of the "total cross-section," which is the probability per unit distance travelled by a gamma photon of its undergoing any reaction at all. The probability of the photon escaping reaction can be expressed as an exponential, the negative exponent of which is the product of the distance travelled and the total cross-section. Gamma photons which have so far escaped any reaction at all are termed "primaries." By making use of this expression, the flux of primaries is readily calculated. To allow for the effect of scattered photons, this flux is multiplied by a "build-up" factor.

Absorption of a thermal neutron generally gives rise to the prompt emission of gamma photons, known as "capture gammas." In the case of thermal neutrons entering a slab of material of thickness T, the net current density of capture gammas leaving either face of the slab is given in

Fig. 1 in which L is the neutron diffusion length. Curves are plotted for various values of gamma "energy" cross-section x neutron diffusion length.

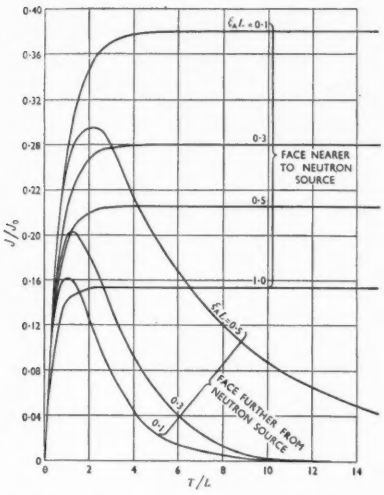


Fig. 1. Relative capture gamma flux leaving faces of a slab, plotted against slab thickness.

Apart from emitting a capture gamma, a nucleus which absorbs a thermal neutron may become radioactive, and decay by undergoing several successive disintegrations each of which may be accompanied by the emission of gamma photons, known as "radioactive decay gammas." The rate per unit volume at which the radioactive nuclei are created is given by the product of the thermal neutron flux and the "activation" cross-section.

Radioactive atoms also occur in the fission products of irradiated nuclear fuel. The numbers of atoms of the various active isotopes created by one thermal fission have been tabulated.

Given the rate of formation of active atoms, their subsequent disintegration can be traced from the law that the rate of disintegration of a particular isotope at any instant is directly proportional to the number of atoms of the isotope present at that instant. Knowledge of the number and energy of gamma photons emitted per disintegration then enables the corresponding source strength of gamma rays to be determined.

Shielding

The "maximum permissible level" of radiation corresponds to a flux of 1,200 and 30 neutrons per sq. cm. per sec. for thermal and fast neutrons, respectively, and from 1,200 to 7,000 photons per sq. cm. per sec. for gamma radiation as the photon energy varies from 5 to 0.5 MeV. In many instances the radiation received can be kept down to this level through keeping sufficiently far away from the source, that is, through "shielding by distance." With a nuclear reactor core, the theory outlined above enables suitable shielding materials to be selected and their performance to be evaluated. Radiation due to activation of the reactor coolant can also be estimated.

Energy is released in a shield of amount equal to that lost by each gamma photon and of amount 2 MeV for every fast neutron thermalized. This energy is subsequently transferred as heat, and imposes temperature rise limitations on reinforced concrete.

Future development should be devoted to cheaper shields, a more exact theory of neutron shielding, and the thermal-stress resistance of reinforced concrete.

INSTITUTION OF CHEMICAL ENGINEERS

Paper presented at the Geological Society, Burlington House, London, W.1, on March 6, 1956.

"Horizontal Mixer-Settler Equipment for Liquid-Liquid Extraction" *by F. Roberts, B.Sc., A.M.I.C.E., and B. T. Bell (Chemical Engineering Division, A.E.R.E., Harwell)*

The main factors in the design of horizontal mixer-settlers are discussed and illustrated by experimental work on a multistage box contactor and on a battery of four separate cylindrical units. It is concluded that it is possible and advantageous to use a simple marine-type propeller to provide a mixing and a pumping action. Recirculation within the equipment is discussed with particular reference to its use as a means of controlling phase ratios and interface levels.

Paper presented at the Royal Institution, Albemarle Street, London, W.1, on March 20, 1956.

"The Application of Fluidisation Techniques to Nuclear Reactors—A Preliminary Assessment" *by J. B. Morris, Ph.D., A.R.I.C., C. M. Nicholls, B.Sc.(Eng.), A.R.I.C., M.I.C.E., and F. W. Fenning, B.A. (A.E.R.E., Harwell)*

A preliminary survey leads to several conclusions regarding the possible nuclear reactors employing the fluidization technique. Fuel investment considerations lead the authors to favour reactors working with "thermal" rather than "fast" neutrons for initial study. While the neutron balance can be disturbed by changes in temperature and pressure, the most sensitive variable in a fluidized system will be the concentration of the moderator and fuel in the volume of the fluidized bed. Gradients of temperature will be very small within the bed.

A useful amount of heat can be extracted from a fluidized bed by simple gas cooling only if powders are used that are coarser than the sizes which have hitherto been normal in industrial practice and if gas under pressure is employed. While hydrogen is the most favourable gas for use with coarse solids, the differences between the gases considered are so slight that a final choice would probably be made on grounds other than heat removal.

Of the cases considered for liquid fluidization, pressurized water has the best heat transport capacity for a given size of particle and temperature rise. In non-pressurized systems the liquid metals sodium and lithium give the best heat removal over the whole range of solid densities. Since the temperature rise which can be tolerated for pressurized water is much lower than for liquid metals, the latter give the more favourable over-all heat removal (transfer plus transport). When the solids are transported by the fluid, as in the case of slurries, the fluid velocities required are much higher than in the fluidized beds and hence greater amounts of heat can be transported. A mixed phase system would give favourable heat removal.

There are formidable problems involved and aspects other than heat removal will rule out some systems which appear at first sight attractive. Any fluidized system that is to be developed beyond the research stage will require engineering to a standard not dreamt of in present industrial practice.

INSTITUTION OF MINING AND METALLURGY

On March 22 and 23 a symposium on the Extraction Metallurgy of Some of the Less Common Metals was held in the lecture hall of the Royal Society of Arts under the auspices of the Institution of Mining and Metallurgy, 44 Portland Place, London, W.1. Twenty-two papers in all were presented. With the small space available only a very brief synopsis of each can be given.

"Some General Chemical Principles in Extraction of Metals from Low-grade Ores" *by A. J. E. Welch, Ph.D., A.R.C.S., D.I.C. (Reader in Inorganic Chemistry, Imperial College of Science and Technology)*

The present paper is a review of a number of recent processes in which chemical concentration methods are predominantly applied to low-grade ores. Its aim is to bring out the general pattern of such processes, to indicate the unit-process steps needing more fundamental study, and to guide the process chemist to outstanding fields of development.

"Purification by Solvent Extraction" *by J. M. Fletcher, M.A., Ph.D. (A.E.R.E., Harwell)*

Three types of solvent extraction are considered in relation to their potentialities for purifying various metals. Solvent extraction in purification is applicable to certain metals produced on an annual scale of up to about 20,000 tons. For metals produced on a scale of 20 tons or less, the use of expensive organic reagents may well be justified. The merits of solvent extraction are compared with those of other methods with particular reference to tributyl phosphate.

"Studies in the Chlorination of Some Complex Ores—Wolframite, Vanadinite and Chromite" *by E. A. Pokorny, D.Sc., F.R.I.C., F.I.M., M.R.I. (Consulting Chemist and Metallurgist)*

The author presents data accumulated from experiments on the chlorination of the three ores mentioned in the title when treated with chlorine, anhydrous HCl, and chlorine with an excess of hydrogen.

"An Oxide-Chloride Conversion Process for the Extraction of Certain Metals" *by A. R. Gibson, B.Sc., and J. H. Buddery, Ph.D. (Respectively C.E.O. and S.S.C., A.E.R.E., Harwell)*

A method is described whereby some metallic oxides may be converted to chlorides in solution in alkali or alkaline earth chlorides. A fluid melt substantially oxygen-free is generated. Metal may be precipitated and recovered from this. The possible chemical actions involved are examined and a tentative theory put forward based on experiments with uranium dioxide and thoria.

"Metallurgical Developments in the Recovery of Some of the Less Common Metals in Canada" *by L. E. Djingheuzian, A.R.S.M., Member (Senior Ore Dressing Engineer, Division of Mineral Dressing and Process Metallurgy, Mines Branch, Ottawa)*

The paper discusses examples of developments in the metallurgy of the following less common metals in Canada: niobium and tantalum, selenium and tellurium, and lithium. The first two groups are representative of commercial operation and lithium of research.

"Extraction of Some Less Common Metals from Smelter and Refinery Intermediates at La Oroya, Peru (Selenium, Tellurium and Thallium)" *by W. E. Koeppel, D.Sc., and A. K. Schellinger, B.A.(Eng.), M.S., Ph.D., M.A.I.M.E. (Assistant Director of Research and Research Consultant, Cerro de Pasco Corporation)*

Recovery of selenium and tellurium from anode residue plant cupel dusts and slags under the high-altitude conditions prevailing at Oroya is described with emphasis on local problems of extraction and marketability. Thallium from lead blast furnace fume is traced through the cadmium plant circuit and its extraction from leach solutions is discussed. Production of high-purity thallium metal from dichromate precipitate is described and marketability discussed.

"The Chemical and Physical Concentration of Uranium Ores" *by S. W. F. Patching, A.R.S.M., B.Sc.(Eng.), M.A.I.M.E., Member (Leader, Mineral Dressing Group, A.E.R.E., Harwell)*

The present position of the treatment of uranium ores is reviewed, with special reference to the way in which physical and chemical methods of concentration are used in relation to each other.

"The Recovery of Uranium from Sulphate Leach Solutions by Anion Exchange" *by T. V. Arden, Ph.D., B.Sc., F.R.I.C., Member (Chief Metallurgist, The Permutit Co. Ltd.)*

A brief summary of uranium leaching technique and type of liquors which result is followed by an account of the precipitation methods which have been proposed or tested for this work, with reasons for their not being adopted. The original discovery of the ion exchange process and early American and British work in this field are described. Details are then given of modern ion exchange plants for the recovery of uranium.

"Factors Influencing the Magnesium Reduction of Uranium Tetrafluoride" *by J. Harper, B.Sc., A.I.M., and A. E. Williams, B.Sc., A.I.M. (U.K.A.E.A., R. and D. Branch, Springfields)*

Experimental work on the reduction of uranium tetrafluoride with magnesium for up to 5 kg. uranium scale is described. Side reactions which can take place in the reduction and which can influence the efficiency of the process and the quality of the metal billet are considered. A technique is described which gives a high density uranium billet with a high over-all reduction efficiency.

"Pilot Plant Concentration of Mindola Uranium Ore" *by M. L. Fitzgerald, Member, and D. F. Kelsall, M.A. (Acting Superintendent and Senior Metallurgist, Research and Development Division, Rhoanglo Mine Services Ltd.)*

The paper describes a pilot plant campaign undertaken to investigate the removal of carbonates by a straight grinding and flotation circuit, with provision for the incorporation of gravity scalping before flotation, should this prove to be desirable.

"The Production of High-Purity Vanadium Metal" *by E. Foley, B.Sc., A.R.I.C., M. Ward (Mrs.), B.A., and A. L. Hock, B.Sc., Ph.D., F.R.I.C. (Senior Research Chemist, Research Chemist, and Chief Chemist, Magnesium Elektron Ltd.)*

A survey of the methods used up to 1948 suggested that the reduction of a suitable chloride by magnesium should form a sound basis on which to develop a process for the technical scale extraction of high-purity vanadium. Recently a pilot plant producing 40-45 lb. batches of vanadium sponge has been brought into operation.

"Processes for the Extraction of Vanadium" *by C. Tyzack, B.Sc., Ph.D., and P. G. England, B.Sc., (P.S.O. and S.S.O. U.K.A.E.A. (I.G.) (Culcheth)*

Details are given of experimental work which has been done on the extraction of ductile vanadium by oxide and halide reduction. The calcium reduction of both V_2O_5 and V_2O_3 is described and the factors which influence the production of the metal in a powder form by chlorination and hydrogen reduction is also gone into.

"Flotation of Vanadium Ore from the Abenab West Mine of South West Africa Company" *by M. G. Fleming, B.Sc., Ph.D., M.I.M.M. (Senior Lecturer in Mineral Dressing, Royal School of Mines, London.)*

Fundamental flotation characteristics of vanadium minerals and the development of a process for concentrating vanadinite, descloizite and cerussite from the complex Abenab West ore are described. The effects of natural water impurities on the flotation process are examined and methods of overcoming their depressant action considered.

"The Selection of a Process for Development for the Production of Pure Niobium" *by G. K. Dickson, B.Sc., F.R.I.C., and J. A. Dukes, A.R.I.C. (U.K.A.E.A. (I.G.), R. and D. Branch, Warrington)*

A review is made of the chemistry of five separate processes which have been devised or studied as methods of extracting pure niobium. The factors taken into account when considering which of these processes should be developed to the pilot-plant scale are discussed. Some details of the relative costs of the various processes are given.

"The Extraction of Pure Niobium by a Chlorination Process" *by A. B. McIntosh, B.Sc., A.R.T.C., F.R.I.C., F.I.M., and J. S. Broadley, B.Sc., Ph.D., A.R.I.C., A.I.M. P. G. England, B.Sc. (P.S.O. and S.S.O., U.K.A.E.A. (I.G.), Culcheth)*

The various stages in a new process for extracting pure niobium from its ores or ferroniobium by chlorination and hydrogen reduction are described. Details are given showing how tantalum can be separated from niobium on a pilot-plant scale by the preferential hydrogen reduction of the mixed niobium and tantalum pentachloride.

"Distillation of Volatile Chlorides as a means of obtaining Pure Niobium" *by B. R. Steele, B.A., Ph.D., and D. Geldart, M.Sc. (U.K.A.E.A. (I.G.))*

The equipment and theoretical data required to separate niobium from tantalum, tungsten and iron by fractionation of their volatile chloride are described. This has been shown to be a convenient means of obtaining pure niobium which could easily be developed to a plant scale.

"Beryllium Production at Milford Haven" *by P. S. Bryant, B.Sc., A.M.I.Chem.E. (Production Manager, Chemical Group, Murex Ltd.)*

Each stage of the modified Coraux method for the production of BeO adopted at Milford Haven is described, followed by details of the production of hydroxide/carbon briquettes and crude $BeCl_2$ and its purification. There is then an account of the electrolysis of fused chloride.

"The Preparation of Beryllium Metal by Thermal Reduction of the Fluoride" *by L. J. Derham, A.I.M., and D. A. Temple, Ph.D., B.Sc., A.R.S.M., A.M.I.M.M. (Imperial Smelting Corporation, Ltd., Avonmouth)*

The paper deals with the pilot plant preparation of beryllium metal from beryllium hydroxide. Various methods of fluxing the solid reaction product, magnesium fluoride, are described and different techniques for collecting and cleaning the beryllium beads are discussed.

"Purification of Metals by Intermediate Formation of their Stable Halide Vapours with Application to Beryllium and Titanium" *by P. Gross, D.Phil., and D. L. Levi M.A., B.Sc. (Fulmer Research Institute, Stoke Poges)*

Metals of which vapour pressures are too low for their evaporation at practicable temperatures may be distilled by a reversible endothermic reaction. The conditions of the reactions and the factors influncing the purity of the distillate are discussed. Beryllium and titanium are given as examples.

"The Extraction of Thorium from Monazite" *by A. Audsley, B.Sc., Ph.D., F.R.I.C., R.Lind., B.Sc., and P. G. England, B.Sc. (U.K.A.E.A. (I.G.), R. and D. Branch, Springfields)*

A number of processes which might be used for the preparation of thorium metal from rock are reviewed. Details are given of purification processes based on chlorination and on solvent extraction of concentrates prepared from the rock by sulphuric acid breakdown. The products of these purification processes are then reduced to metal by calcium.

"Some Investigations into the Extraction of Titanium by Fused Salt Electrolysis" *by F. L. Bett, B.Met.E., M.Eng.Sc., B. S. Hickman, M.Sc., G. M. Willis, M.Sc., and H. K. Worner, D.Sc., F.I.M. (Research Officer, Research Scholar, Senior Lecturer in Chemical Metallurgy, and Professor of Metallurgy, University of Melbourne.)*

Methods of producing titanium electrolytically are reviewed and difficulties outlined. The paper briefly describes the work done over the past seven years in Melbourne University, which shows that the metal can be produced by electrolysis of lower valency chlorides of titanium in molten salt carrier electrolytes.

"The Manufacture of Hafnium-free Zirconium" *by F. Hudswell, M.A., F.R.I.C., and J. M. Hutcheon, B.Sc., A.R.I.C. (A.E.R.E., Harwell)*

The paper reviews the following principles and methods for separating zirconium from hafnium: fractional crystallization, distillation, vapour phase reaction, adsorption, ion exchange and chromatographic processes, liquid-liquid extraction. The following routes to hafnium-free zirconium metal are discussed in more detail: the U.S. process; the U.S.S.R. process and a suggested process according to methods developed and operated in France and the United Kingdom.

Forthcoming Meetings

British Nuclear Energy Conference

April 5—"The Control and Instrumentation of a Nuclear Reactor" by A. B. Gillespie. "The Control of Nuclear Reactors" by R. J. Cox and J. Walker. "Reactor Control Ionization Chambers" by W. Abson and F. Wade. "Some Design Aspects of Nuclear Reactor Control Mechanism" by G. E. Lockett. At the Institution of Electrical Engineers, Savoy Place, London, W.C.2. 5.30 p.m.

May 3—"Some Problems in the Maintenance of Nuclear Reactors" by H. G. Davey. At The Royal Institution, Albemarle Street, London, W.1. 5.30 p.m.

Incorporated Plant Engineers

April 12—"An Introduction to Atomic Energy" by J. A. Dixon. At Roadway House, Oxford Street, Newcastle. 7.0 p.m.

April 27—"Atomic Energy" by Dr. J. H. Fremlin. At Imperial Hotel, Birmingham. 7.30 p.m.

Institute of Metals

April 10 *to* 13—Spring Meeting. At Church House, Great Smith Street, London, S.W.1. *April* 11—"Metallurgical Research and Development for Nuclear Power" by H. K. Hardy. "Metallurgical Research Problems Associated with Nuclear Energy" by J. G. Ball. "Selection of Canning Materials for Reactors Cooled by Sodium Potassium and Carbon Dioxide" by A. B. McIntosh and K. Q. Bagley. 2.30 p.m. *April* 12—"Powe. Metallurgy" a discussion on published papers including "The Sintering, Fabrication and Properties of Thorium" by M. D. Smith and R. W. K. Honeycombe. 10 a.m. "Rolling Textures and Recrystallization"—a discussion on published papers, including "Deformation and Annealing Textures in Thorium" by R. E. Smallman. 2.30 p.m.

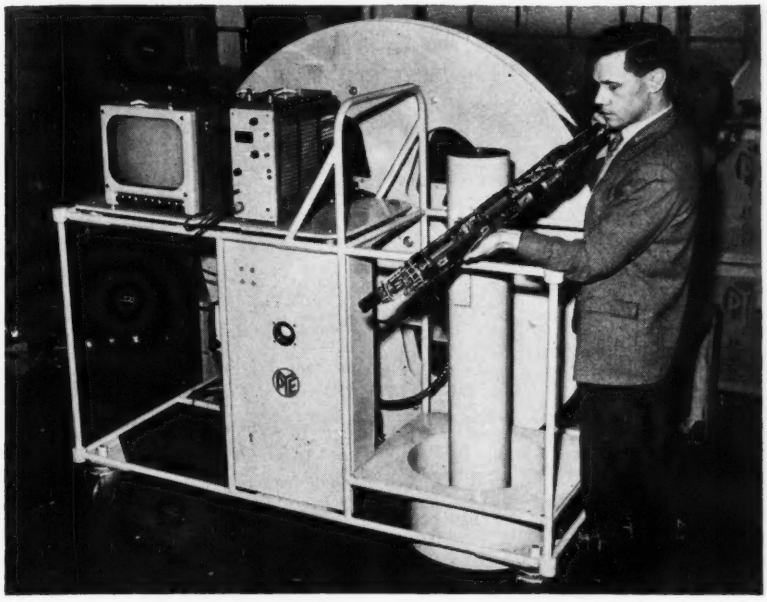
Physical Society and Institute of Refrigeration

April 26—"The Use of Radioactive Techniques in Refrigeration Engineering" by Dr. D. V. Smith. At the Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, S.W.1. 5.30 p.m.

Royal Society of Health

April 24 *to* 27—Annual Health Congress: *April* 26—"Health Hazards from Atomic Radiation" by Dr. M. G. Candau. "Ionizing Radiation: a Problem in Occupational and Public Health" by A. S. McLean. "The Control of Health Hazards from Radioactive Materials" by H. J. Dunster. At the Winter Gardens, Blackpool.

Processes and Equipment



The Pye television camera and trolley-mounted controls.

TV Camera for Reactor Use

A television camera, small enough to be lowered into the core of a reactor through the narrow fuel-loading channels has been developed by Pye Ltd., Cambridge, for the A.E.A. After tests at Harwell it will be used at Calder Hall.

The camera is housed in a thin stainless-steel casing 3½-in. diameter and 30-in. long. For ease of manipulation, it carries its own source of illumination consisting of four small but powerful bulbs grouped round the lens. A rotable mirror enables all-round viewing to be obtained. Remote control is, of course, necessary and, because the camera may be exposed to temperatures up to 200°C., the control cables are enclosed in flexible hose through which CO_2 is pumped for cooling. The camera may be washed down after removal from the reactor to remove radioactive contamination.

A second and similar outfit is now being made for the Authority; it will be used as a stand-by.

Reactor Simulator

Analogue computing techniques are being increasingly applied to the solution of problems associated with nuclear reactor design. In the light of the experience gained in the development of analogue computers such as TRIDAC supplied to R.A.E., Farnborough and AGWAC supplied for the Australian Guided Weapon programme, Elliott Brothers (London) Ltd., Elstree Way, Borehamwood, Herts, have for some time been studying this new field.

The company's nuclear division is currently engaged in manufacturing an analogue computer for reactor power-station kinetics for the industrial atomic energy department of the General Electric Co. Ltd., Erith. This computer has been designed to meet the requirements of G.E.C. for problems associated with gas-cooled graphite-moderated reactors although the flexibility of the machine will allow its use in the design of other forms of reactor. The computer, which normally operates in real time, will solve not only equations concerned with the control and safety of the reactor but it will also provide solutions to heat-exchanger and turbo-alternator transient equations. Designers will be able to study and determine the effects due to variations of parameters in the operation of a nuclear power station.

Welding Electrodes

New electrodes for use on Fusarc automatic welding machines have been brought out by Quasi-Arc Ltd., Bilston, Staffs. Known as Firmec, the electrodes have been designed for welding mild steel in the flat position and are suitable for fillet welding and single-pass butt welds in thicknesses from $\frac{3}{16}$ in. to $\frac{3}{8}$ in.

High welding speeds are possible as a larger size of electrode than normal can be used for any given fillet weld size. Slag detachability is good and a smooth weld surface is obtained.

Firmec electrodes are made to specification B.S.639:1952 and in sizes from 12 s.w.g. to 4 s.w.g.

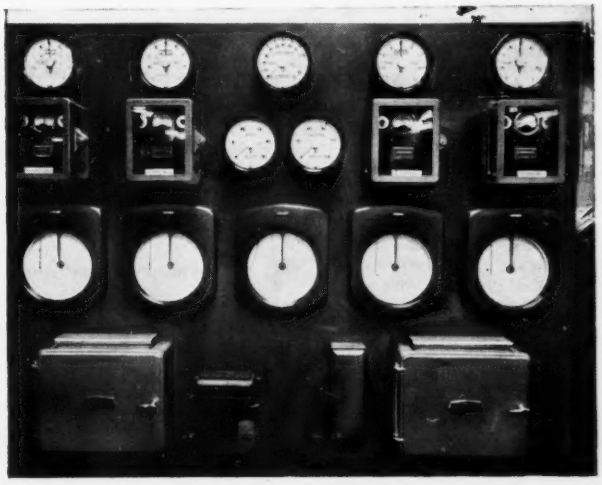
The company has also introduced an electrode for welding mild steel in all positions and giving welds of high radiographic standard. Known as Vertispeed, the electrode is particularly recommended for horizontal-vertical and vertical butt welds.

A portable vacuum recovery unit designed for use with the Quasi-Arc Unionmelt process has also recently been put on the market. It can be supplied as part of a complete Unionmelt installation or as a separate unit. As only a small percentage of the granulated welding composition forms the protective slag covering the weld, the recovery of unfused composition is economic.

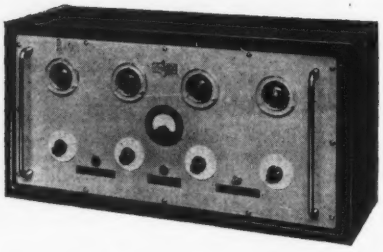
Dry-Chemical Fire Extinguisher

A new pressure-operated dry-chemical fire extinguisher which weighs less than 10 lb. when fully charged, is now being marketed by the Pyrene Co. Ltd., 9 Grosvenor Gardens, London, S.W.1.

Charged with 5 lb. of dry chemical powder, the extinguisher is pressurized with nitrogen up to 150 p.s.i. although it will still operate satisfactorily at pressures as low as 100 p.s.i. The pressure is constantly recorded on a gauge embodied in the head of the operating valve, a feature which provides the operator with an instant check on the condition of the extinguisher. It is offered with either a pistol-grip or squeeze-grip head. The nozzle projects the contents in the form of a fan-shaped jet with an angle of over 30°; the range is about 8 ft.



Control panels and off-gauge meters for four β-gauges measuring weight per unit area on a tandem callender set-up. The material being checked is a rubber-covered fabric used by the Firestone Tyre and Rubber Co. Ltd. for tyre manufacture. The equipment was supplied by Isotope Developments Ltd., Beenham Grange, Berks.



Londex model EBC electronic counter for batching duties.

New Counters

Two new electronic counters have been introduced by Londex Ltd., 207 Anerley Road, London, S.E.20. The model EC is intended for counting under industrial conditions, and operates at a rate of up to 500 per sec. The length of the pulse and the interval between pulses are such that the instrument is well suited to counting articles which are small or are moving at a fast rate.

Model EBC has been designed primarily for controlling the batching of articles. With a maximum count rate of 500 per sec. and pulse length and pulse interval not less than one millisec. the unit will batch at a rate up to 4 times a second the number of objects batched being dependent on the counting rate.

Metal Powder Deposition

The T.L.B. process for the deposition in powder form of hard facing alloys was developed some time ago and is now widely used in a variety of industries. Among the facings being deposited are nickel boron silicon and austenitic nickel.

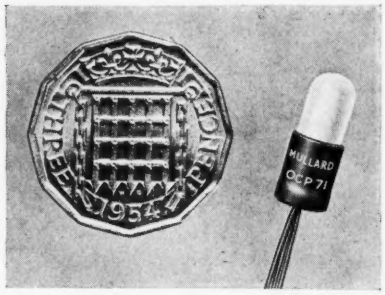
Now the patentees, Dewrance and Co. Ltd., Great Dover Street, London, S.E.1, have produced special machines for effecting a weld-deposited hard facing on a flat annular surface. The machines are semi-automatic in operation, controls being provided for regulating the rotation speed of the table, oxygen-acetylene mixture, and elevation and traverse of the torch nozzle. Gas jets pre-heat the workpiece, the heat being controlled to maintain the required temperature and to stress-relieve the casting after depositing.

Combination Rolling Mill

It has been announced by Albert Mann's Engineering Co. Ltd., Basildon Industrial Estate, Essex, that they are now manufacturing under licence the Stanat two-high/four-high rolling mill.

Conceived as a combination mill, it can be converted from a four-high to a two-high set-up in 20 min. The design allows heavy pass reductions without lateral distortion of the work rolls and also provides heavy rolling torque capacity. Further, several sizes of roll are available from $2\frac{1}{2}$ in. to $\frac{1}{4}$ in., making possible the production of very thin gauge strip. With the four-high arrangement, strip down to less than 0.001 in. finishing gauge can be rolled.

Each back-up roll bearing has a load bearing of 150,000 lb., equal to a maximum roll separating force of 300,000 lb., and each 12-in. pinion gear and $3\frac{1}{2}$-in.-diameter universal spindle is capable of transmitting 80,000 lb.-in. torque. In the two-high arrangement, the 8-in. by 8-in. back-up rolls become work rolls for taking heavy bites.



Illustrating the extremely small size of the new Mullard OCP71 germanium photo-transistor.

Germanium Phototransistor

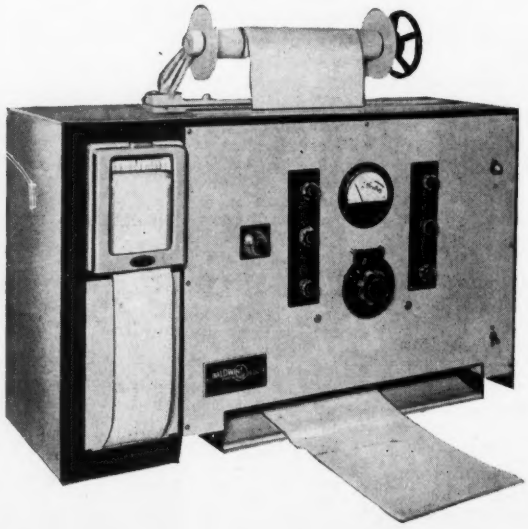
A germanium phototransistor has been introduced by Mullard Ltd., Century House, Shaftesbury Avenue, London, W.C.2. Designated type OCP 71, it is similar in form to a conventional low-power junction transistor and costs little more. It is sensitive enough to operate direct a relay of normal type. The circuits are extremely simple and may be nothing more than the phototransistor connected in series with the relay coil and a 12V or 18V battery.

Normally only two connections to the phototransistor are needed, but if operation over a wide range of temperatures is required, the base electrode can be fed with a small positive compensating bias to maintain the dark current at a low level. At 25°C the dark current is not more than 300 micro-amp.; this is small when compared with the light current which can be of the order of 5 to 10 mA. The spectral response is peaked in the infra-red region (1.55μ) but continues into the visible light region.

At the preferred direction of incident light the sensitivity is from 1.5 to 4 mA, measured at Vc=−2V and with uniform illumination of 75 ft-candle; in the end-on direction, sensitivity is between 0.5 and 1.3 mA. The optical cut-off frequency is in the region of 3 kc/s.

The OCP 71 is suitable for industrial control applications such as photoelectric counters, speed measurement, liquid level control, edge detection and burglar alarms. Its small size also makes it particularly suitable for tape and punched-card reading.

To be introduced at the Hanover Fair—a pocket-sized GM counter with built-in loudspeaker. The makers, Herfurth GMBH, Hamburg-Altona, Germany, have also introduced a radiation monitor with automatic alarm adjustable from 2 to 50 mr/h. Some of the instruments shown work on the ionization chamber principle and will measure alpha and beta radiation as well as gamma.



Baldwin transverse profile Atomat machine.

Weight Variation Measurement

The Baldwin transverse profile Atomat for measuring the weight variations of paper, board and plastics, is now being fitted with its own amplifier. This makes it a self-contained unit no longer dependent on the Atomat beta-ray thickness gauge. Transverse-cut samples are fed through the unit and any weight variations are plotted automatically on a recorder.

The manufacturers are Baldwin Instrument Co. Ltd., Brooklands Works, Dartford, Kent.